

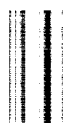
MSC INTERNAL NOTE NO. S-PA-8M-030

APOLLO MISSION TECHNIQUES
MISSION C-PRIME LUNAR (ALTERNATE 1)
TRANSLUNAR MIDCOURSE CORRECTIONS
AND LUNAR ORBIT INSERTION
VOLUME I
TECHNIQUES DESCRIPTION
REVISION A

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APOLLO SPACECRAFT PROGRAM OFFICE
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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FOREWORD

This Translunar Midcourse and Lunar Orbit Insertion Mission Techniques Document is one of seven documents describing the C-prime lunar mission. The others are as follows:

- Saturn V/Apollo Launch Aborts
- Earth Parking Orbit and Translunar Injection
- Lunar Orbit Activities
- Transearth Injection, Midcourse Corrections, and Entry
- Tracking Data Selection Controllers Procedures
- Contingency Procedures

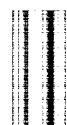
These documents contain the officially approved guidance and control sequence of events, the data flow, and real-time decision logic for the C-prime lunar mission. The purpose of these documents is to insure the compatibility of all related MSC and supporting contractor activities.

For each mission phase, a Data Priority Working Group has been established under the direction of Chief, Apollo Data Priority Coordination, ASPO. These groups, which are comprised of representatives of MSC and support contractors, hold frequent meetings to coordinate their various associated activities and develop agreed upon mission techniques. TRW assists in the development of the techniques and documents them for ASPO. After formal review by ASPO, E&DD, FCOD, FOD, GAEC, MDC, MIT, NR, and TRW, a document such as this one is issued.

This document is the final version of the C-prime Lunar (Alternate 1) Transearth Midcourse Corrections and Lunar Orbit Injection document (Revision A). The vertical bars which appear in the margins of the text and flow diagrams represent changes to the last edition of this document.

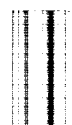
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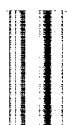
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NOMENCLATURE

ARIA	Apollo Range Instrumentation Aircraft
AOH	Apollo Operations Handbook
AOS	acquisition of signal
ASCP	attitude set control panel
ASPO	Apollo Spacecraft Program Office
BAP	best adaptive path
BMAG	body mounted attitude gyro
BRC	basic reference coordinate system
BSS	boresight star (PAD data)
BT	burn time (PAD data)
CDR	Commander
CLA	longitude constrained landing area
CM	command module
CMC	Command Module Computer
CMP	Command Module Pilot
COAS	crew optical alignment sight
CSM	command and service module
DSKY	CMC display and keyboard
EMS	entry monitoring system
EPT	earliest possible time
FDAI	flight director attitude indicator
FOV	field-of-view
FPS	feet per second
FR	free return
g. e. t.	ground elapsed time

NOMENCLATURE (Continued)

GET 0.05 g	ground elapsed time to 0.05 g entry condition (PAD data)
GETI	ground elapsed time of ignition (PAD data)
GDC	gyro display coupler
GNCS	CSM guidance, navigation, and control system
ΔH	CMC horizon bias
H_A	apogee altitude
HOPE	An RTACF program used to process optical sighting data
H_P	perigee altitude
IMU	inertial measurement unit
IRIG	inertial rate integrating gyroscope
IU	instrument unit (S-IVB)
K_1	end of mission fuel reserves for fast return with contingencies
K_2	minimum end of mission fuel reserves for lunar orbit mission
LAT	latitude of resultant landing point after abort maneuver (PAD data)
LLOS	landmark line-of-sight
LMP	Lunar Module Pilot
LOI	lunar orbit insertion
LONG	longitude of resultant landing point after abort maneuver (PAD data)
LOS	loss of signal
MCC	midcourse correction
MCC-H	Mission Control Center - Houston
MGA	middle gimbal angle

NOMENCLATURE (Continued)

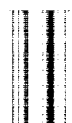
MSFN	Manned Space Flight Network
NAV	navigation
NBD	null bias drift
NR	North American Rockwell
ORDEAL	orbital rate drive device (to establish local vertical FDAI display in pitch)
P23	Cislunar Navigation Program
P27	CMC Update Program
P30	CMC External ΔV Program
P40	SPS Thrust Program
P41	RCS Thrust Program
P47	Thrust Monitor Program
P52	IMU Realign Program
PAD	data voiced to crew from ground and recorded by crew for future use
PIPA	pulse integrated pendulous accelerometer
PLA	planned landing area
PTC	passive thermal control
P _{TRIM}	SPS pitch trim gimbal angle (PAD data)
RCS	reaction control system
REFSMMAT	transformation matrix from BRC reference to CSM stable member inertial coordinates
R, P, Y	roll, pitch, and yaw IMU gimbal angles (PAD data)
RSS	root sum square
RTACF	Real-Time Auxiliary Computing Facility
RTCC	Real-Time Control Center
RTGO	range to go for entry maneuver (EMS) (PAD data)

NOMENCLATURE (Continued)

SC	spacecraft
SCS	stabilization and control system
SCT	scanning telescope
SFT	shaft angle for SXTS (PAD data)
SM	service module
SXT	sextant
SXTS	sextant star for ignition attitude check (PAD data)
S-IVB	third stage of Saturn launch vehicle
SPA	BSS pitch angle (COAS)
SPS	service propulsion system
SXP	BSS X-position (COAS)
THC	translational hand controller
TIG	time of ignition
TL	translunar
TLI	translunar injection
TM	telemetry
TRN	trunnion angle for SXTS (PAD data)
UNZAP	state vector transfer from LM locations in CMC to CSM locations
VI	P47 DSKY display of inertial velocity
VIO	inertial velocity setting for entry maneuver (EMS) (PAD data)
WT	CSM weight (PAD data)
W-matrix	error transition matrix used in the CMC Navigation Updating Program (P23)
Y_{TRIM}	SPS yaw trim gimbal angle (PAD data)

NOMENCLATURE (Continued)

ZAP	state vector transfer from CSM location in CMC to LM location
ΔR	P23 display of magnitude of the difference between the CMC position vector before and after incorporation of star measurement
ΔV	velocity correction, P23 display of magnitude of the difference between the CMC velocity vector before and after incorporation of star measurement
ΔVC	EMS ΔV counter setting for maneuver (PAD data)
ΔVT	total impulsive ΔV (PAD data)
$\Delta V_X, \Delta V_Y, \Delta V_Z$	P30 velocity to be gained components in local vertical coordinates



1. INTRODUCTION

The following text and flow charts present the guidance and navigation events and real-time decisions which must be made for the C-prime lunar mission beginning from translunar injection cutoff through the lunar orbit insertion maneuver.

The objective of this report is to document a standard acceptable procedure for verification and usage of navigation and guidance data together with alternate or backup procedures in the event of a primary guidance, navigation and control system (GNCS) failure. Routine procedures and operations not pertinent to the objectives are omitted for the sake of clarity.

The procedures shown in the charts reflect the following key ground rules:

- a) MCC-H always provides all maneuver targeting for midcourse corrections and LOI-1 and LOI-2.
- b) All burns (midcourse corrections, LOI-1 and LOI-2) will use the GNCS external ΔV mode.
- c) Midcourse corrections (MCC's) will be performed earlier than the scheduled times if the minimum ΔV safe-return trajectory correction is greater than 70 feet per second for the first MCC and greater than 10 feet per second for all subsequent MCC's.
- d) A properly operating GNCS is mandatory for LOI.

Figure 1 shows the sequence of events for the translunar and lunar orbit insertion phases of a typical C-prime lunar mission.

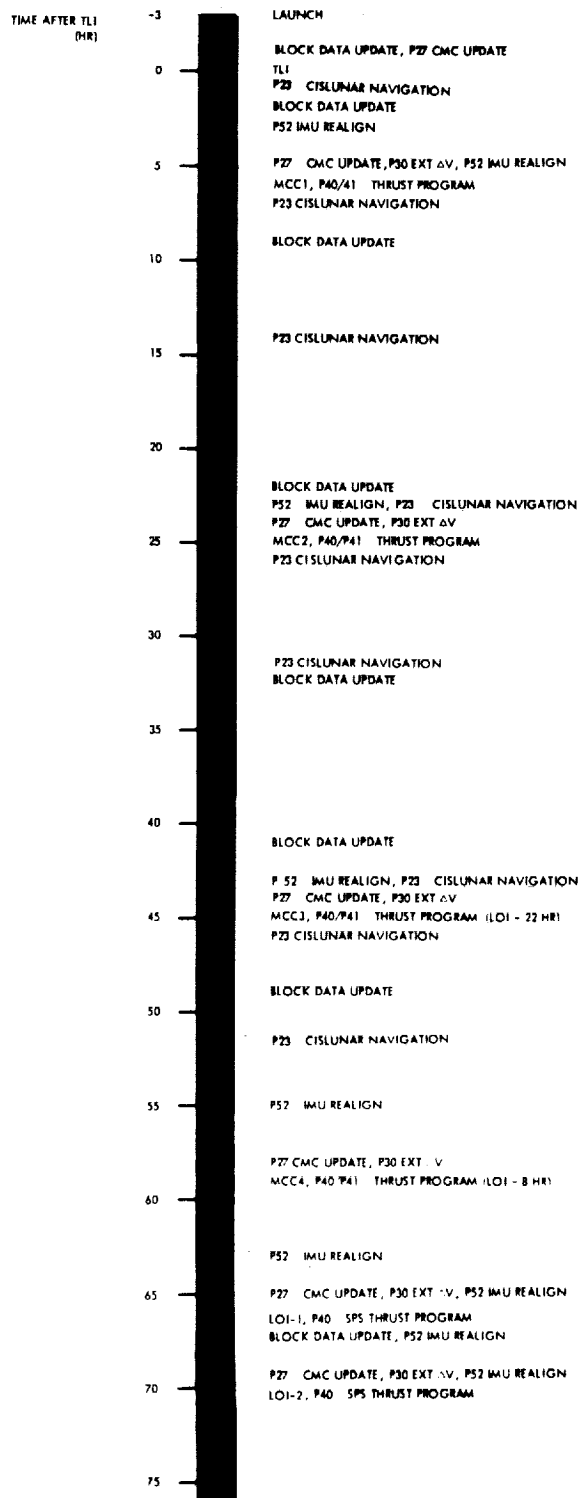


Figure 1. Typical Mission C-prime Sequence of Events for TL MCC and LOI

2. LOI GO/NO-GO PROCEDURE

Prior to committing to the lunar orbit insertion (LOI) burn, the GNCS must be evaluated to ascertain if it is operating within specified limits. (Reference 1). This is accomplished in a manner similar to the translunar injection (TLI) go/no-go procedure. The technique makes use of velocity component strip charts during TLI and vector comparison display data during translunar coast. The strip chart data consist of a comparison between the S-IVB and GNCS velocity components in the inertial measurement unit (IMU) coordinates. Changes in trends or a large gradual divergence (beyond established limits) between the two systems are cause to suspect that one system is malfunctioning. To determine the system that is malfunctioning, orbital parameter differences between MSFN tracking and GNCS TM sources are compared by use of the vector comparison display during translunar coast. The strip chart parameters also include a comparison between the S-IVB and GNCS inner, middle, and outer gimbal angles.

The following items prevent the LOI go/no-go procedure from being treated in the same manner as the TLI go/no-go procedure.

- a) There is a difference between the instrument unit (IU) and GNCS initial position and velocity vectors prior to TLI (Command Module Computer (CMC) normally has MSFN vector).
- b) There is an initial difference in platform alignments between the two systems due to gyro drifts during launch and parking orbit.
- c) The initial azimuth misalignment will be known and will be input into the Real-Time Control Center (RTCC) and RTACF IU/GNCS difference programs for LOI if no platform alignment is performed prior to TLI ignition.
- d) New orbital decision parameters have been defined, since the ones used for the TLI go/no-go decision are peculiar to circular orbits (Reference 2). This allows use of the vector comparison display.
- e) There is sufficient time during translunar coast to obtain reasonably accurate values of constant gyro drift and accelerometer bias quantities.

The most significant contributor to velocity differences during the TLI burn is the initial misalignment at TLI ignition. However, by evaluating the gimbal angle difference strip charts early in the TLI burn, a measure of the initial misalignment may be obtained which in turn can be used to determine the effect they will have on TLI burn velocity differences. If time permits, the platform will be aligned during parking orbit, thus minimizing the misalignment.

Each of the items discussed in the preceding paragraphs will be factored into the definition of the LOI go/no-go procedure or into the limits established to base a decision. (Page 5-23).

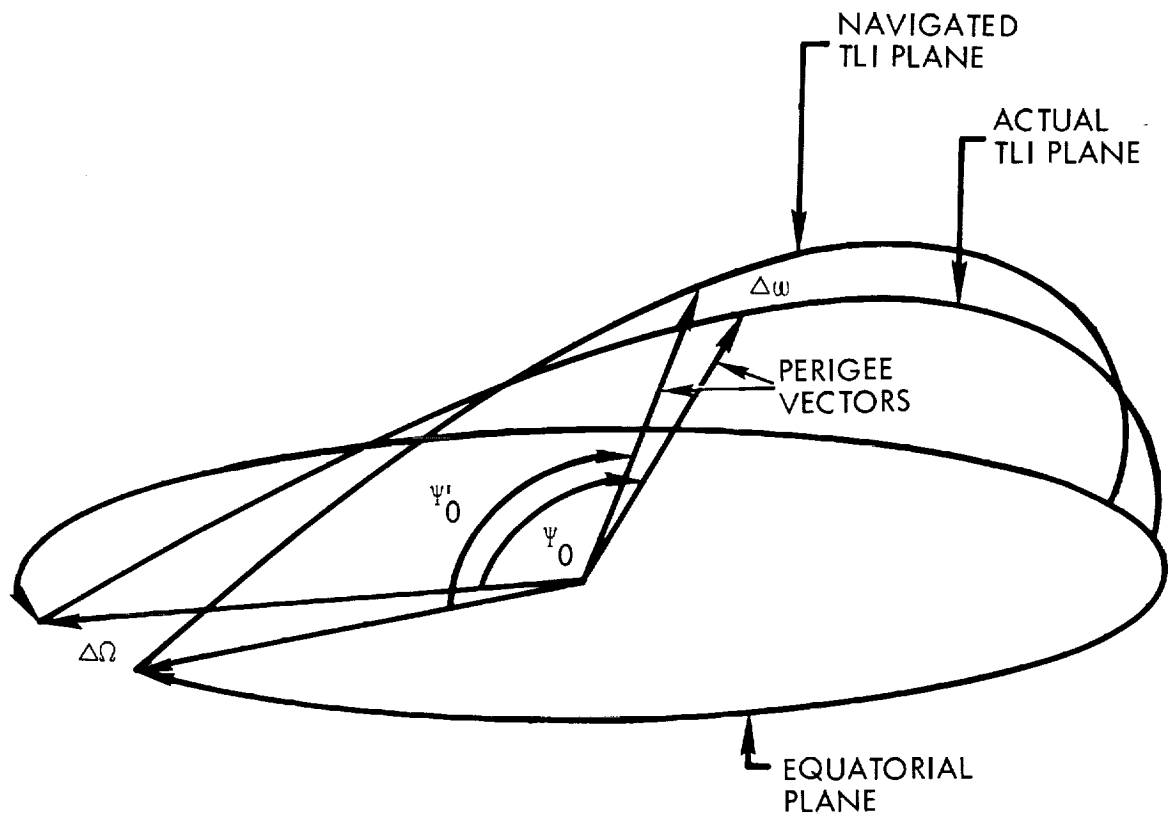
2.1 GNCS AND S-IVB IU TLI VELOCITY COMPARISONS

The velocity difference strip charts consist of a set of four charts which indicate the difference between the S-IVB IU and GNCS total (ΔV_c) and component velocities ($\Delta \dot{X}_c$, $\Delta \dot{Y}_c$, $\Delta \dot{Z}_c$) at any time during the TLI burn. The comparisons are made in IMU stable member coordinates after the velocity vectors have been time synchronized. The velocity differences will be forced to zero at the start of the TLI burn, and the gravitational integral effects are removed in order to detect the sensed velocity errors.

Table 1 shows the acceptable strip chart limits at TLI cutoff that are used to determine a satisfactory GNCS/IU comparison (Reference 3). These limits are 23 feet per second for all four parameters (Reference 3).

2.2 GNCS AND MSFN ORBITAL PARAMETER COMPARISONS

During the translunar coast the orbital decision parameters are evaluated using the vector comparison display data. Three comparisons between the IMU navigation state and the MSFN tracked state are used to determine the IMU navigation system performance during the TLI maneuver. For detecting velocity magnitude errors, resulting from in-plane accelerometer biases or scale factors, the semimajor axis difference (Δa) is used. For detecting in-plane errors that are normal to the thrusting direction, resulting from Y-axis gyro drifts, the difference in argument of perigee ($\Delta \psi_0 = \psi_0 - \psi_0'$) is used (Figure 2). Cross range errors are detected by a parameter related to the wedge angle ($\Delta \omega$) between the IMU estimated TLI conic plane and MSFN tracked TLI conic plane. The



- $\Delta\omega$ - WEDGE ANGLE
- $\Delta\Psi_0$ - ARGUMENT OF PERIGEE DIFFERENCE ($\Psi'_0 - \Psi_0$)
- $\Delta\Omega$ - RIGHT ASCENSION DIFFERENCE

Figure 2. Angular Relationship Between Orbital Decision Parameters

wedge angle ($\Delta \omega$) will provide a clear indication of cross range velocity errors that occur during the TLI maneuver. The parameter displayed is the estimated nodal cross range velocity ($\Delta \dot{w}_{\max}$) between the IMU estimated TLI plane and the MSFN tracked TLI plane when the two orbits are scaled down to circular earth parking orbits.

The LOI no-go limits for the $\Delta \psi_0$ and $\Delta \dot{w}_{\max}$ orbital decision parameters are 0.095 degree and 22 feet per second, respectively (Table 1). The Δa no-go limit is a function of the g.e.t. of TLI ignition (Reference 3). A typical no-go value for Δa for the nominal lift-off time is 114 million feet.

2.3 LOI GO/NO-GO PROCEDURE

The LOI go/no-go procedure consists of the following steps:

- a) Decision parameter differences are revised to reflect initial misalignments determined in earth parking orbit (input required from gimbal angle strip charts processed during parking orbit) (Reference 4).
- b) MCC-H will calculate and evaluate accelerometer bias calculated during the coasting period. If the error is sufficiently large to suspect that failure is evident (greater than 0.164 foot per second squared) then LOI is no-go (Reference 5). If the bias is greater than 0.003 foot per second squared, then an accelerometer update is performed (Reference 6). The velocity strip charts and orbital parameter limits are revised to compensate for the known bias.
- c) MSC-H will calculate and evaluate constant gyro drift errors and initial misalignments calculated during translunar coast. If this error indicates that a GNCS failure is evident (greater than 1.5 degrees per hour), then LOI is no-go (Reference 5). If the drift error is greater than 0.075 degree per hour, then a gyro update is performed (Reference 6). The calculated drift values are used to update orbital parameters and strip chart limits.
- d) After the strip chart velocity component limits have been compensated for known accelerometer bias, platform misalignments, and gyro drift (if necessary), the data are examined to determine if the allowable limits have been violated and if definite trend changes exist. If the data are acceptable, then LOI is go at this point. If the data limits are exceeded or unfavorable trend

changes exist, then a temporary LOI no-go is given until the orbital decision parameters have been investigated.

- e) It is not necessary for MCC-H to evaluate the orbital decision parameters (differences between GNCS and MSFN tracking) unless the strip chart limits are violated. These parameter differences will be revised to include the effects of initial platform misalignment (Reference 4). If the orbital parameter differences are within limits, then LOI is GO at this point.
- f) The vector comparison display will be used to evaluate GNCS performance after each midcourse correction is completed. If the trajectory is determined to have been significantly perturbed and if it is determined that a GNCS failure is the cause of the perturbation, then LOI is no-go.

A program which generates the required velocity and gimbal angle strip charts has been developed for use in the RTACF (Reference 7). S-IVB and GNCS velocity vectors and gimbal angles will be supplied on tape. This tape will be used to drive the programs which, in turn, will generate the strip charts to be used to formulate the go/no-go decision.

If a ground station or ship is in sight of the TLI burn, then the required data can be obtained real time. If ARIA data must be used, then it will be transmitted sometime during translunar coast. If all TLI data are lost, LOI is go if all other checks are favorable. FSD has indicated that they can process the requested data within 3 hours after it is received. ARIA data will probably be available to the RTCC within 11 hours after TLI. This will provide adequate time to process and analyze the results in order to make the LOI go/no-go decision.

Table 1. LOI Go/no-go Limits

<u>Decision Parameter</u>	<u>Definition</u>	<u>Limit</u>
ΔV_c	Saturn-G&N velocity difference in IMU stable member coordinates	23 ft/sec
$\Delta \dot{X}_c$		23 ft/sec
$\Delta \dot{Y}_c$		23 ft/sec
$\Delta \dot{Z}_c$		23 ft/sec
Δa	MSFN-G&N difference in semimajor axis	114×10^6 ft*
$\Delta \psi_0$	MSFN-G&N argument of perigee	0.095 deg
$\Delta \dot{w}_{\max}$	MSFN-G&N difference in nodal crossrange velocity	22 ft/sec

* This is a typical value for the nominal lift-off time (Reference 3).

3. TRANSLUNAR MIDCOURSE PHILOSOPHY

The purpose of translunar (TL) midcourse corrections (MCC's) is to maintain the SC as close as practical to the nominal free return (FR) trajectory. During the translunar phase the SC will probably never be exactly on a free return trajectory intersecting the entry corridor. This is because the Manned Space Flight Network (MSFN) uncertainty in estimating the vehicle state vector can propagate into entry flight-path angles which lie far outside of the entry corridor. However, analysis has shown a clear perilune (greater than 20 nautical miles) is probable after the first midcourse correction has been executed and the burn residuals nulled to within 0.2 feet per second.

Four TL-MCC's are planned at the times shown below in Table 2. The reduction in perilune below 60 nautical miles, due to a 1-foot-per-second velocity error in the worst direction at these times is also shown.*

Table 2 Perilune Sensitivities at Nominal Midcourse Times

<u>MCC</u>	<u>MCC Time (hr)</u>	<u>Perilune reduction below 60 n mi (n mi/fps)</u>
MCC-1	TLI + 6	36 n mi
MCC-2	TLI + 25	20 n mi
MCC-3	LOI - 22	8 n mi
MCC-4	LOI - 8	4.3 n mi

There are three modes of targeting available for the C-prime lunar mission (Reference 8); the first is FR best adaptive path (BAP). The objective of this mode of targeting is to reduce the sum of the ΔV required for the translunar MCC's and the LOI-1 maneuver to the smallest possible value which will result in the desired lunar orbit. This mode is not used

*Data provided by MPAD-Lunar Mission Analysis Branch.

beyond TLI+30 hours for the following reason: As the MCC maneuver point gets close to LOI, the ΔV tradeoff between performing a given plane change at a MCC or at LOI-1 becomes significant concerning translunar phase ΔV optimizations; that is, a given plane change ΔV at a MCC can reduce the plane change ΔV at LOI-1 by an ever increasing amount as the lunar sphere of influence is approached. Therefore, the FR BAP mode of targeting (which recognizes the small potential ΔV savings) would produce the corresponding plane change tradeoff. Thus the situation could occur where the FR BAP MCC ΔV would begin growing in magnitude even though the previous MCC had been executed perfectly. The situation would be comparable to preplanning a nominal multi-impulse translunar MCC/LOI combination to save ΔV . Since ΔV is not that critical and because it is operationally desirable to freeze the nominal flight profile as early as possible, the FR BAP mode for the latter portion of the translunar coast is undesirable.

Beyond the scheduled time of MCC-2, nodal (XYZ and T) MCC targeting is used. This type of MCC is targeted for the position vector and time of arrival at the nominal node between the lunar approach hyperbolic plane and the desired lunar orbit plane, thus providing a direct coupling with the desired lunar orbit. These nominal nodal targeting objectives are defined by the last previous FRBAP targeting computation; i. e., if the previous FRBAP MCC were executed perfectly (including navigation), the actual ΔV required for a subsequent nodal targeted MCC would be zero. Because of the small MCC errors expected, nodal targeting is extremely close (within 2 or 3 feet per second) to pure free-return targeting.

A third mode of MCC targeting, free return flyby, is available throughout the translunar coast phase as a backup to the FRBAP and nodal modes. Its target objectives are a specified perilune altitude and latitude and earth return flight-path angle for a circumlunar trajectory. The primary disadvantage of using this third mode for MCC for a lunar orbit mission is that it is decoupled from any specified or desired lunar orbit orientation. Thus, it will normally be used for targeting a flyby alternate mission. In the unlikely event the flyby mode were used due to some contingency, it would still be possible to target and execute a LOI maneuver based on the resulting lunar approach trajectory if the perilune

altitude has been kept reasonably low, but it may be impossible to obtain the exact desired lunar orbit orientation.

The three-sigma MSFN uncertainties in velocity for the translunar phase are shown in Table 3. The SPS will be used for MCC ΔV 's greater than 5 feet per second. Below 5 feet per second, the MCC's will be formed with + X RCS translation (Reference 9).

3.1 FIRST MIDCOURSE CORRECTION

It is highly desirable that the MCC-1 procedures allow retention of the capability of placing the SC on a trajectory which safely returns to the earth entry corridor using RCS fuel only. This capability allows a safe return to earth even if the service propulsion system (SPS) burns cannot be performed. Large TLI dispersions may result in this minimum ΔV safe-return trajectory being an earth-centered ellipse rather than circumlunar. Circumlunar minimum ΔV trajectories are of course targeted for a clear perilune.

Whether or not the SPS is functional may not be known until its use is attempted. It is highly probable that the SPS will be required for the first MCC at TLI +6 hours. A backup RCS ΔV solution (to be used in the event the SPS fails to execute MCC-1) is calculated for TLI +6.5 hours. The backup RCS maneuver PAD will be voiced up only if the SPS fails. This RCS correction is the smallest trajectory correction which allows a safe return when applied at that time (or at apogee for the earth-centered ellipse case).

The Real-Time Auxiliary Computing Facility (RTACF) will determine the minimum RCS ΔV required at TLI +6.5 hours or later to target the SC for a safe return to the entry corridor within inclination limits of 90 degrees. This minimum ΔV solution is tested against a decision value of 70 feet per second (Reference 8). The 70-foot-per-second decision value has been tentatively chosen because it is the a priori three-sigma FR BAP MCC-1 at TLI +6 hours and is also well within the full command service module (CSM) total RCS ΔV capability of approximately 180 feet per second. The growth of the three-sigma MCC-1 over the first 6 hours after TLI is shown in Figure 3.

Table 3. Typical Three-Sigma Uncertainty of MSFN Velocity Measurement (Reference 10)

Time from TLI Cutoff (hr)	Velocity Uncertainties (fps)		
	\dot{u}^*	\dot{v}^*	\dot{w}^*
2.00	0.42	1.02	2.85
6.00	0.24	0.81	1.59
10.00	0.18	0.72	1.20
15.00	0.15	0.63	0.96
20.00	0.12	0.51	0.72
25.00	0.22	0.24	0.69
30.00	0.09	0.39	0.54
35.00	0.09	0.36	0.50
40.00	0.09	0.33	0.45
45.00	0.07	0.28	0.36
50.00	0.06	0.24	0.32
55.00**	0.06	0.20	0.28
60.00**	0.14	0.06	0.14
65.00**	0.15	0.06	0.33
67.20(LOI-1)**	2.46	3.57	11.07

* \dot{u} is MSFN three-sigma uncertainty in radial direction.

\dot{v} is MSFN three-sigma uncertainty in horizontal direction.

\dot{w} is MSFN three-sigma uncertainty in out-of-plane direction.

** \dot{u} , \dot{v} , and \dot{w} are in moon reference (earth reference prior to 55 hours).

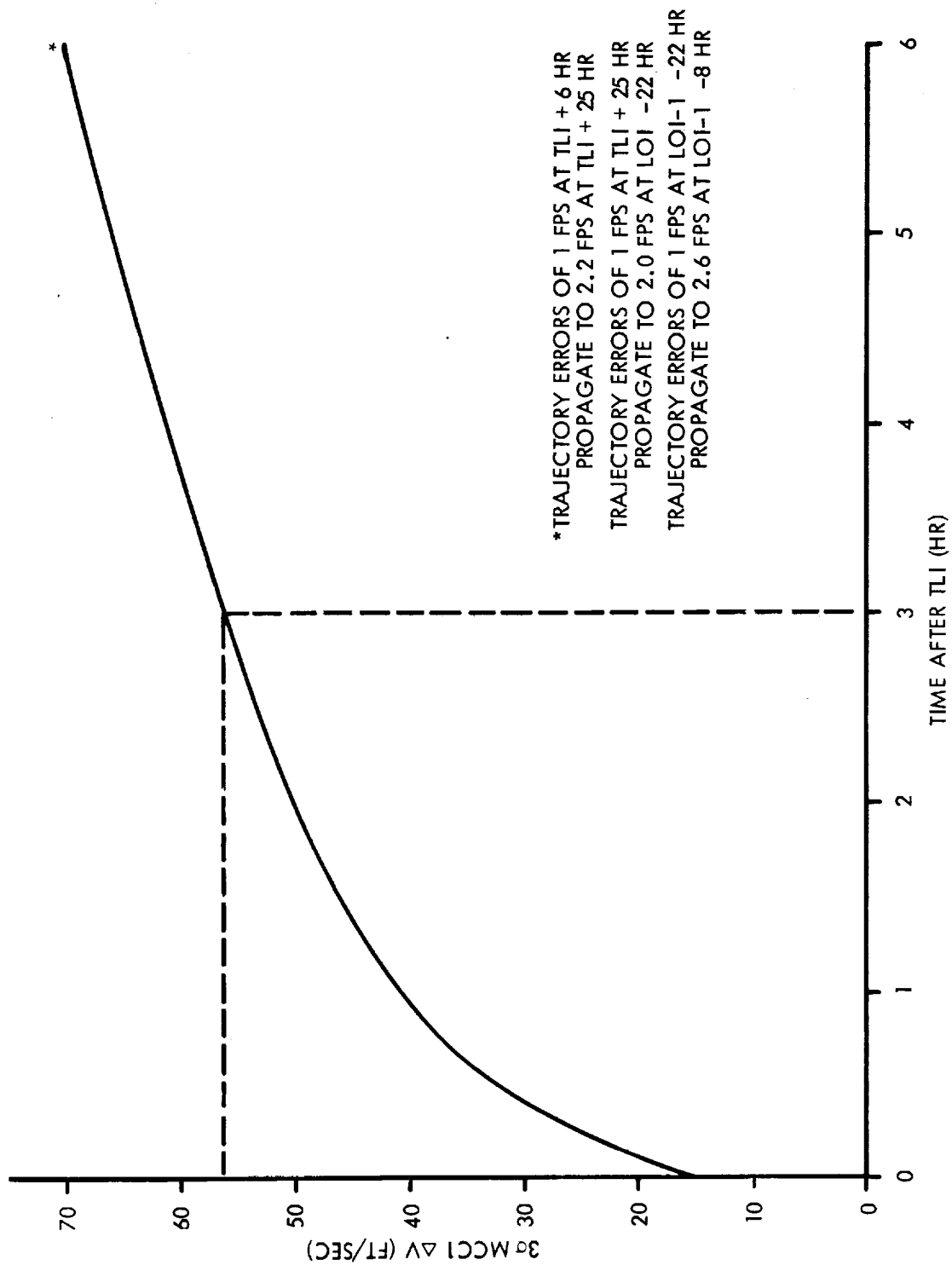


Figure 3. Propagation of Translunar Midcourse Corrections

If the RTACF minimum ΔV solution is nominal (less than 70 feet per second), the RTCC FR BAP MCC-1 solution for TLI +6 hours will be applied unless its use would reduce the end of mission fuel reserves (ΔV_{RES}) to less than K_1 feet per second or is too small (less than 3 feet per second) to be worthwhile (MSFN uncertainty at this time is about 3 feet per second). The value of K_1 , which is a function of launch azimuth and TLI injection opportunity, includes sufficient fuel reserves for a faster transearth return to the prime Pacific landing area (165 degrees west). The faster return times vary approximately from 24 hours at the beginning of the December and January launch windows to 10 hours at the end of the launch windows. The shorter return times are due to an RTCC upper velocity restriction on the entry velocity of 36,323 feet per second. K_1 also includes contingency fuel reserves for: (1) the ability to move the landing point 20 degrees in latitude by applying a correction 24 hours prior to entry (600 feet per second) and (2) extra fuel reserves for the case where all SPS maneuvers have to be performed under SCS control (120 feet per second). This additional ΔV allowance is an RSS combination of 600 and 120 feet per second (612 feet per second).

If the TLI +6 hours MCC-1 fuel reserves are less than K_1 or if the RTACF RCS solution (TLI +6.5 hours) is greater than 70 feet per second, a FRBAP MCC-1 will be applied at the earliest possible time (EPT). This is about TLI +3 hours. However, if the backup RCS ΔV required at the earliest possible time is greater than the maximum RCS reserves, there is no advantage in performing an early MCC-1, and targeting will be for TLI +6 hours. Should the EPT FR BAP MCC-1 solution leave fuel reserves of less than K_2 feet per second, an alternate mission is required. The value of K_2 is the smallest ΔV reserve with which it is practical to commit to a lunar orbit mission. This end of mission reserve allows a return time of 24 hours greater than the intermediate speed return but with no allowance for contingencies. Typical curves of K_1 and K_2 are shown in Figure 4. These curves are for a 21 December launch at the first TLI opportunity. The values of K_1 and K_2 are the relative fuel reserves with respect to that required for a nominal intermediate speed return. Values of ΔV_{RES} greater than zero allow for faster than nominal returns and values of ΔV_{RES} less than zero result in slower return times.

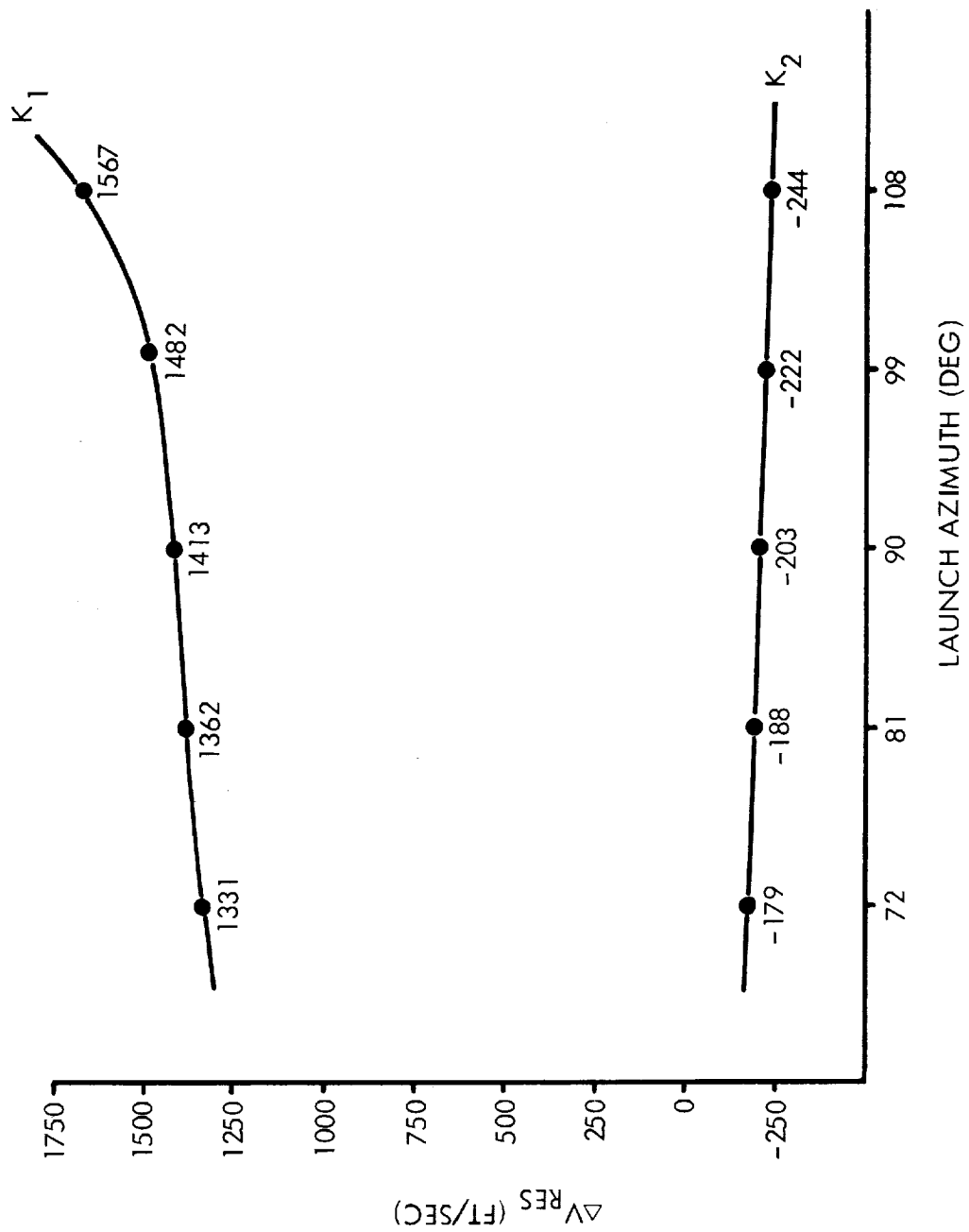


Figure 4. Typical ΔV End of Mission Reserve Limits
(Data Provided by MPAD - Lunar Mission Analysis Branch)

If the available end of mission fuel reserves are barely greater than K_2 and MCC-1 is successfully performed, the SC will be on a free-return trajectory. If this low fuel reserve case occurs, a real-time decision is required in order to commit to LOI.

3.2 SECOND MIDCOURSE CORRECTION

A FR BAP MCC-2 will be performed at the scheduled time (TLI+25 hours) if the MCC ΔV is between 1 and 10 feet per second. If it is greater than 10 feet per second (Reference 8), it will be performed at the EPT. Below 1 foot per second, it is not worth performing at all, considering the MSFN uncertainty. The 10-foot-per-second limit was chosen to be high enough to insure a low probability of having to perform the midcourse correction earlier than planned, yet the 10 feet per second is low enough to insure that more than sufficient SM/RCS reserves exist to trim the trajectory to a free return landing if the SPS were lost sometime prior to TLI+25 hours.

3.3 THIRD AND FOURTH MIDCOURSE CORRECTIONS

The third and fourth midcourse corrections will nominally be targeted with the nodal (XYZ and T) mode. An additional mode, flyby, is available for non-orbital missions.

The third midcourse will be performed if its magnitude is greater than 1 foot per second, and residuals will be nulled to within 0.2 foot per second. MCC-4 will be performed regardless of its magnitude and residuals will also be nulled to 0.2 foot per second.

It is considered highly desirable to keep the SC trajectory near the nominal. These two MCC's will be executed at their scheduled times unless their magnitude is greater than 10 feet per second. The rationale for the 10 feet per second number is explained in Section 3.2. If either of these scheduled MCC's exceeds 10 feet per second, it will be performed at the EPT unless it still exceeds 10 feet per second. In this case, something serious has occurred, and a real-time decision will be made to either perform the EPT nodal MCC or to perform a flyby MCC.

4. TRANSLUNAR NAVIGATION

The basic ground rule is for MCC-H to provide the navigation function as long as communications are maintained with the SC. Nominally, the MCC's will be performed under GNCS control using the external ΔV mode and the MSFN state vector. The typical program sequence around a MCC will be P52, P23, P27, P30/P40 (41) and P23 as shown in Figure 5. The MSFN vectors that are uplinked to the CMC are placed in the LM slots. The CMP transfers the vector from the LM slots to the CSM slots prior to the burn to establish the external ΔV coordinate system (UNZAP). After the burn, the CMP transfers the CSM vector back to the LM slots (ZAP) to keep a state vector onboard not modified by further navigation sightings. This transferring of the state vector is consistent with the transearth phase where the ZAP/UNZAP procedure is required. Sometime prior to LOI and following MCC-4, MCC-H will place the MSFN vector in both the LM and CSM slots.

In addition to the maneuver target loads, state vector, and CMC PAD data sent to the SC by the ground, block data maneuver PAD's will also be sent. This block data will be used for an abort if communications are lost at a later time. If a block data abort is required, P23 will be selected after the burn, the W-matrix initialized and navigation sightings taken to perform the backup navigation function required for subsequent MCC's.

The translunar sighting schedule was not designed to provide for state vector comparisons to validate onboard or ground navigation. The results of these sightings may be used, however, to modify the transearth sighting schedule, procedures, or possibly W-matrix initialization values. These sightings will be evaluated and compared with current error models to evaluate the capability of the backup transearth navigation system.

Star/earth horizon sightings scheduled at TLI +1.5 hours are evaluated by MCC-H to determine the earth horizon bias (ΔH) above the Fischer ellipsoid used by the CMC. Such sightings are scheduled again at TLI +14 hours, when ΔH errors are negligible, to establish sextant biases, if any, that may have influenced the earlier determination of ΔH .

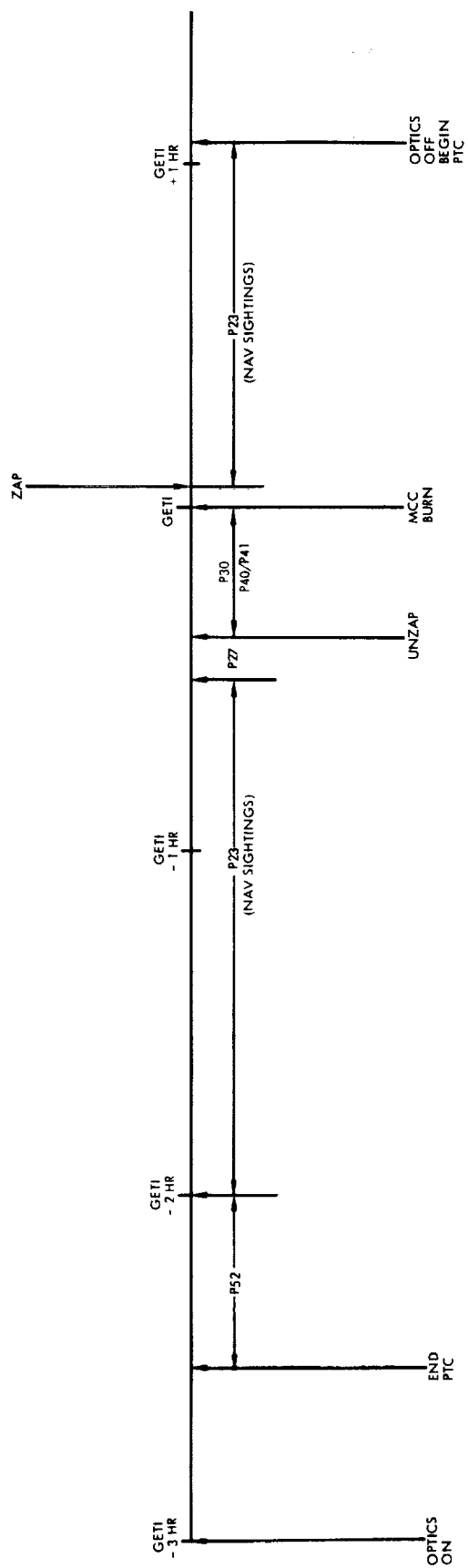


Figure 5. Typical MCC and Navigation Sighting Sequence

If the ΔH determined from the first sightings is different from that in the E-memory of the CMC by more than 4.5 nautical miles, then the ΔH will be updated in the CMC. This uplink will occur at approximately TLI +7 hours. Subsequently, MCC-H will verify this update or issue a new ΔH value at about TLI +18 hours after processing of the second sightings has been completed (Reference 11).

Translunar optical sighting data will be processed off-line (in the HOPE program of the RTACF) to obtain estimates of state vector and perilune altitude. This state vector will not be used directly to validate MSFN because (a) HOPE is not yet a thoroughly tested and proven program, (b) the accuracy of lunar horizon sightings has not been verified and (c) the RTCC/MSFN is inherently self checking because of independent data sources and data types. RTCC/MSFN will always be used as the source of navigation information for mission control unless detailed investigation of its performance can determine errors. Such investigations will be instigated if (Reference 11):

- a) Optics biases >0.036 degree when residuals are computed from the RTCC vector, but less than this value relative to the RTACF/MSFN vector.
- b) RTCC/MSFN and RTACF/MSFN differ in perilune prediction by greater than 20 nautical miles.
- c) RTCC/MSFN and CMC optics differ in perilune prediction by greater than 20 nautical miles anytime after LOI -20 hours.
- d) RTCC/MSFN and RTACF optics differ in prediction of perilune by greater than 20 nautical miles anytime after LOI -20 hours.

A typical sighting schedule, shown in Table 4 and Figure 6, calls for both horizon and landmark sightings. If cloud cover on the way out precludes obtaining the star landmark sightings (only one set of these sightings are planned for C-prime mission), then all sighting activity will be deleted for that scheduled period. That is, horizon sightings will not be performed in lieu of the star landmark sightings.

The sighting data will be processed to update the CSM state vector if the position (ΔR) and velocity (ΔV) difference displays after a mark are satisfactory. IF ΔR exceeds 50 nautical miles and/or ΔV exceeds 50 feet

Table 4. Typical Navigation Sighting Schedule*

<u>Time of Sightings (hr:min)</u>	<u>Sightings</u>	<u>Stars Used (Octal)</u>	<u>Number of Marks</u>
TLI +1:30	Star/Earth Near Horizon	14	1 set of 3
	Star/Earth Far Horizon	15	2 sets of 3
	Star/Earth Far Horizon	16	2 sets of 3
TLI +6:20	Star/Earth Landmark #10	15	1 set of 3
	Star/Earth Landmark #10	16	2 sets of 3
TLI +14:30	Star/Earth Far Horizon	16	2 sets of 3
	Star/Earth Far Horizon	22	3 sets of 3
TLI +23:40	Star/Earth Far Horizon	16	1 set of 3
	Star/Earth Far Horizon	22	1 set of 3
	Star/Earth Near Horizon	26	1 set of 3
TLI +25:20	Star/Earth Far Horizon	16	1 set of 3
	Star/Earth Far Horizon	21	1 set of 3
	Star/Earth Far Horizon	22	1 set of 3
	Star/Earth Near Horizon	26	1 set of 3
TLI +31:20	Star/Earth Far Horizon	16	1 set of 3
	Star/Earth Far Horizon	22	1 set of 3
	Star/Earth Near Horizon	26	1 set of 3
LOI -24:10	Star/Lunar Near Horizon	33	2 sets of 3
	Star/Lunar Near Horizon	37	1 set of 3
	Star/Lunar Far Horizon	42	1 set of 3
	Star/Lunar Far Horizon	45	1 set of 3
LOI -21:50	Star/Earth Far Horizon	16	1 set of 3
	Star/Earth Far Horizon	22	1 set of 3
	Star/Earth Near Horizon	26	1 set of 3
LOI -16:50	Star/Lunar Near Horizon	33	3 sets of 3
	Star/Lunar Near Horizon	37	2 sets of 3

*Reference 12

per second, the mark is rejected, and the sighting will be repeated. If the differences are repeatable, the new mark will be accepted (Reference 13).

A summary of the SXT constraints relating to navigation sightings follows (Reference 14):

- a) Trunnion Angle - The trunnion angle must be greater than 2 degrees and less than 50 degrees, unless the sun is within 45 degrees of the LLOS, in which case the maximum trunnion is 45 degrees.
- b) Star Magnitude - The star must be bright enough to be acquired against the background and tracked across the LLOS target.

Minimum Star Magnitude

	<u>Earth</u>	<u>Moon</u>
Horizon	3	3.5
Landmark	1	2.5

- c) Scattered Light - The background illumination due to sunlight scattered off the optical elements must not be so bright that it obscures either the star or the horizon image.
- d) Sun Elevation - The local sun elevation angle at the tangent point for horizon measurements or at the landmark must be high enough to illuminate the target without distortion.

Minimum Sun Elevation Angle

	<u>Earth</u>	<u>Moon</u>
Horizon	10 deg	5 deg
Landmark	10 deg	5 deg

- e) Landmark Slant Angle - Due to optical foreshortening and atmospheric thickness, landmarks with large slant angles are unusable. (The angle is between vertical at the landmark, and the LLOS). This constraint does not apply to horizon measurements.

Maximum Slant Angle

<u>Earth</u>	<u>Moon</u>
45 deg	60 deg

The preliminary optical rules which are applicable to the translunar phase, are as follows (Reference 15):

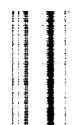
- a) One landmark is to be combined with at least three stars to form three star/landmark sightings (if three stars are available) with the stars as symmetrically distributed about the line of sight to the landmark as possible.
- b) A sighting interval is to consist of at least three star/horizon sightings (two stars as close to the orbit plane as possible and one star as far out of the orbit plane as possible) or at least three star/landmark sightings.
- c) A sighting is to consist of three marks.

The navigation sighting intervals should be scheduled so that the following conditions are satisfied (Reference 15):

- a) Immediately following a period of length Δt not to exceed 3 hours in a non-PTC mode, five times Δt be spent in a PTC mode (thermal constraint)
- b) No sightings within 1-1/2 hours preceding a midcourse correction and 1/4 hour following a midcourse maneuver

The sextant calibration routine will be exercised at least every half hour while navigation sightings are in progress. The sextant calibration will be repeated until agreement of at least two checks (not necessarily sequential ones) are within 0.003 degrees (Reference 13).

If an abort burn is performed during translunar coast, the W-matrix will be reinitialized at its launch value of 3300 feet, 3.3 feet per second for onboard processing of the transearth sighting data (Reference 22).



5. DISCUSSION OF FLOW DIAGRAMS

The following checks and procedures are followed for the translunar midcourse and lunar orbit insertion phases of the C-prime mission.

5.1 IMU ALIGNMENTS AND REFSMMAT's

Periodic IMU alignments (P52) to particular REFSMMAT's will be made during the C-prime mission. All realignments are verified with auto optics to a third star. If at any time the gyro torquing angles indicate an off-nominal IMU drift, frequent P52's are performed to assess the drift performance. The LOI-1 no-go compensated gyro drift limit has been set at 1.5 degrees per hour (Reference 5). That is, the GNCS will be considered failed if the IMU drift shifts more than 1.5 degrees per hour from the initial compensated value. The compensation is updated if the drift rate exceeds 0.075 degree per hour (Reference 6).

Since the GNCS will be powered up through the whole mission, the selection of a REFSMMAT or REFSMMAT's through the entire translunar coast phase must be made. The launch pad alignment REFSMMAT will be kept as long as possible until the final MCC. This is desirable since it would mean no new REFSMMAT's and coarse alignments to contend with, and it would be acceptable alignment for use with translunar abort block data and for the barbecue type of thermal control. However, the required MCC's cannot be guaranteed to avoid gimbal lock (defined in this case as middle gimbal angle >45 degrees) with any preselected REFSMMAT; i.e., the MCC's can be in any direction. Thus, if gimbal lock is predicted to occur for a particular MCC maneuver, a preferred REFSMMAT will be used. The platform is realigned to the launch REFSMMAT after the MCC in this case.

For the last MCC (nominally at LOI -8 hours) a switch to the nominal LOI-2 preferred alignment will be made unless gimbal lock would occur. For the gimbal lock case, the launch pad alignment would be retained unless it too would produce gimbal lock, in which case a preferred REFSMMAT would be used. If either the launch or preferred REFSMMAT was used for the last MCC, the IMU will be realigned to the LOI-2 REFSMMAT after MCC completion. The LOI-2 preferred REFSMMAT is to be used for all

lunar operations including LOI-1, LOI-2, and TEI. The LOI-2 REFSMMAT is such that if a horizontal, in-plane, heads-up, posigrade burn were being made at LOI-2, the gimbal angle (FDAI) readout would be approximately 0,0,0. (R-P-Y).

5.2 PIPA BIAS UPDATE

Periodic checks are made by MCC-H of the PIPA bias values. A change of 0.003 feet per second per second in any axis requires an update (Reference 6). The LOI-1 no-go limit on the PIPA bias is 0.164 feet per second per second (Reference 5). That is, the GNCS will be considered failed if the PIPA bias shifts more than 0.164 foot per second per second from the initial compensation.

5.3 BLOCK DATA MESSAGES

Frequent MCC maneuver and abort block data PAD messages are voiced up. The combined MCC maneuver and block data PAD is shown in Table 5. The nominal block data times are shown in Table 6. The block data solutions through TLI +44 hours result in direct (noncircumlunar) trajectories with landing in the primary area (165 degrees west). The LOI -8 hour abort is targeted for a circumlunar trajectory to the contingency landing area (CLA) and with a perilune between 200 and 1500 nautical miles. The perilune +2 hours solution is targeted for the fastest return to the CLA provided an SPS burn is required to hit water. However, if the present trajectory already allows a water landing within the RCS capability this block data maneuver will be targeted for the minimum ΔV required to hit water.

During earth orbit, two abort maneuver PAD's will be voiced to the crew. The first will be an abort for TLI +90 minutes to be used for SC systems problems. The second will be the first block data time shown in Table 6 (TLI +4 hours). The subsequent block data will be voiced to the crew so that at least two future maneuvers are onboard. Maneuvers will be corrected for trajectory updates as required. Block data for burn attitude gimbal angles will be for the launch pad REFSMMAT with the exception of the post-perilune block data which will use the LOI-2 REFSMMAT. The case of loss of communications while the CMC has other than the launch pad REFSMMAT will only result in the PAD gimbal angle

Table 5. Maneuver Pad

COMMENTS		MANEUVER									
											PURPOSE
											PROP/GUID
											WT N47
R	ALIGN		0	0							P _{TRIM} N48
P	ALIGN		0	0							Y _{TRIM}
Y	ALIGN		0	0							HRS GET1
			0	0	0						MIN N33
			0								SEC
											ΔV_X N81
											ΔV_Y
											ΔV_Z
		X	X	X							R
		X	X	X							P
		X	X	X							Y
		+									H _A N44
											H _p
		+									ΔVT
		X	X	X							BT
		X									ΔVC
		X	X	X	X						SXTS
		+							0		SFT
		+						0	0		TRN
		X	X	X							BSS
		X	X								SPA
		X	X	X							SXP
			0								LAT N61
											LONG
		+									RTGO
		+									VIO EMS
											GET .05G

Table 5. Maneuver Pad (Continued)

Notes

- PURPOSE is the name of the maneuver
- PROP/GUID is propulsion and guidance selected
- WT is the CSM weight (lb)
- P_{TRIM} and Y_{TRIM} are respectively the pitch and yaw trim SPS gimbal angles (deg)
- GETI is the time of ignition
- ΔV_x , ΔV_y , ΔV_z are the P30 velocity to the gained components in local vertical coordinates (fps)
- R, P, Y are the IMU gimbal angles at the time of ignition for the maneuver (deg)
- H_A , H_p are the altitude of apogee and perigee, respectively above launch pad radius (n mi)
- ΔVT is the total inertial velocity impulse (fps)
- BT is the burn time (min:sec)
- ΔVC is the EMS ΔV counter input
- R_{ALIGN} , P_{ALIGN} , Y_{ALIGN} are the backup GDC or IMU alignment angles
- SXTS is the sextant star to be used for the SC ignition attitude check.
- SFT is the sextant shaft angle for the SXTS (deg).
- TRN is the sextant trunnion angle for the SXTS (deg).
- BSS is the boresight star for an ignition attitude check using the COAS (as required).
- SPA is the BSS pitch angle (COAS) (as required) (deg).
- SXP is the BSS X position (COAS) (as required) (deg).
- LAT and LONG are, respectively, the latitude and longitude of the resultant landing point following the abort maneuver (deg).
- RTGO is the range to go for the entry maneuver (EMS) (n mi).
- VIO is the EMS inertial velocity for the entry maneuver (fps).
- GET .05 g is the estimated ground elapsed time to the 0.05 g level of acceleration for the entry maneuver (hr:min:sec).

The last five items of the maneuver PAD are essentially an abbreviated entry PAD.

data for monitoring not being usable. The ΔV data are not affected, however, being in local vertical (P30) coordinates.

Table 6. Nominal Abort Block Data Schedule

<u>Time Block Data Is Sent to SC</u>	<u>Execution Time for Block Time</u>
TLI - 1:10	TLI + 1:30 TLI + 4:00
TLI + 2:00	TLI + 4:00 (Update) TLI + 11:00
TLI + 9:00	TLI + 11:00 (Update) TLI + 25:00 LOI - 8:00
TLI + 22:00	TLI + 25:00 (Update) TLI + 35:00 LOI - 8:00 (Update)
TLI + 32:00	TLI + 35:00 (Update) TLI + 44:00 LOI - 8:00 (Update)
TLI + 41:00	TLI + 44:00 (Update) LOI - 8:00 (Update) Perilune + 2:00
TLI + 48:00	LOI - 8:00 (Update) Perilune + 2:00 (Update)

5.4 SCS DRIFT CHECK

Periodically the IMU gimbal angles are compared to the SCS gimbal angles (GDC/BMAG's 2). The allowable limit (three-sigma) for the SCS drift check is 10 degrees per hour for all axes (Reference 16). If the GDC fails to indicate the IMU attitude within the allowable limits, the SCS is switched to the backup rate mode (BMAG's 1) and the GDC is realigned to the IMU. The test is then repeated. If the SCS FDAI (using BMAG's 1) does not indicate the allowable SCS drift, then the GDC is probably operating greater than 3σ (the IMU could be drifting). If the GDC drift is within the data acceptance limits after switching to BMAG's 1, BMAG's 2 are operating greater than 3σ . The BMAG/GDC failure limit is 15 degrees per

hour. After the test, the GDC (if operational) is aligned periodically to the IMU.

5.5 EMS TEST

Nominally, before all burns, a test of the EMS ΔV counter and accelerometer bias is made (AOH procedures). The accelerometer bias failure limit is 0.1 foot per second per second (Reference 17). Failure to pass the test prior to the LOI-1 burn does not inhibit LOI-1, since time is used for LOI backup SPS cutoff and is sufficient for TEI backup SPS cutoff.

5.6 CMC UPDATES

The CMC update program, P27, is selected by either MCC-H or the crew to update the CMC. The update may include state vectors, target parameters, PIPA and IRIG biases, REFSMMAT's, etc. The state vector is sent up prior to a maneuver. In between maneuvers, the state vector is uplinked to the CMC LM slots at the discretion of MCC-H. The PIPA and IRIG bias are uplinked whenever their allowable limits are exceeded. The REFSMMAT's that are uplinked are described in Section 5.4. The REFSMMAT is always sent up last whenever the CMC is updated with other data to insure a correct REFSMMAT is in the CMC, as other uplinked data may result in destroying the REFSMMAT within the CMC.

A list of psuedo-landing sites landmarks has been prepared. The landmark selected for observations is determined by the launch time. The landmark corresponding to the scheduled launch time will be loaded into the CMC prelaunch. If the launch is not performed at the scheduled time the new landmark coordinates will be entered in the CMC during translunar coast using the universal uplink.

5.7 PREBURN PROCEDURES FOR ALL SCHEDULED BURNS

This section describes the typical preburn activities for scheduled GNCS controlled translational maneuvers. The first activity consists of performing an IMU alignment (P52). The alignment is checked using auto-optics to a third star. For scheduled MCC's (except MCC-4), the Cislunar Navigation Program (P23) is next used to obtain navigation data for MCC-H. Following the CMC update (P27) and the maneuver PAD message, the External ΔV program is exercised. The thrust program is either P40 or P41.

The crew monitors the CMC auto maneuver to the burn attitude and adjusts the outer gimbal angle to the PAD value. The SFT and TRN angles are set to PAD values. If the SXTS is in the SXT FOV then the GNCS is go. If the SXTS is not in the SXT FOV, then the auto optics is used to drive the SXT to the SXTS (PAD data). The TRN angle must indicate the PAD value within 1 degree in order to proceed with the GNCS. For LOI-1 if this 1-degree optics check is failed, LOI-1 is no-go. For MCC's however, the burn is executed with the SCS if the GNCS problem cannot be resolved. The crew has the option to use the BSS and COAS to verify the SC attitude. If the SXTS or BSS cannot be seen, then LOI-1 is no-go. A preburn horizon check will also be made for LOI-1. The desired horizon location at a particular time before TIG will be computed after launch. If it is determined that the horizon is more than 5 degrees from its expected location, then LOI-1 is no-go.

After the ignition attitude is verified, the GDC is aligned (to 0-0-0 for MCC's and to exactly 0-180-0 for both LOI burns). The BMAG's 1 are then uncaged. The crew will monitor these attitude references to determine if the SC is drifting while under GNCS control. The SC is drifting if both the SCS attitude references indicate a drift greater than their respective three-sigma limits in any axis (SCS/GDC - 10 degrees per hour; BMAG's 1 - 1.7 degrees per hour).

The preburn sequence of events for the LOI-1 and LOI-2 burns are shown in Figure 7. The typical sequence for a MCC has been shown previously in Figure 5.

5.8 LOI-1 BURN MONITOR

This section presents the burn monitor functions during the GNCS controlled LOI-1 burn of the C-prime lunar mission. Data limits included in these charts are supplied by MPAD (Reference 18).

It is assumed that certain undetected double failures (both sets of BMAG's or one of the BMAG sets and the primary control system) will not occur during a single SPS burn. This means that if the BMAG's displays disagree, the one that is not nominal is assumed to be failed. If both BMAG's displays are off-nominal, the GNCS is assumed failed. The lunar horizon is not used as an additional vote for LOI burns when all attitude/rate displays are functional.

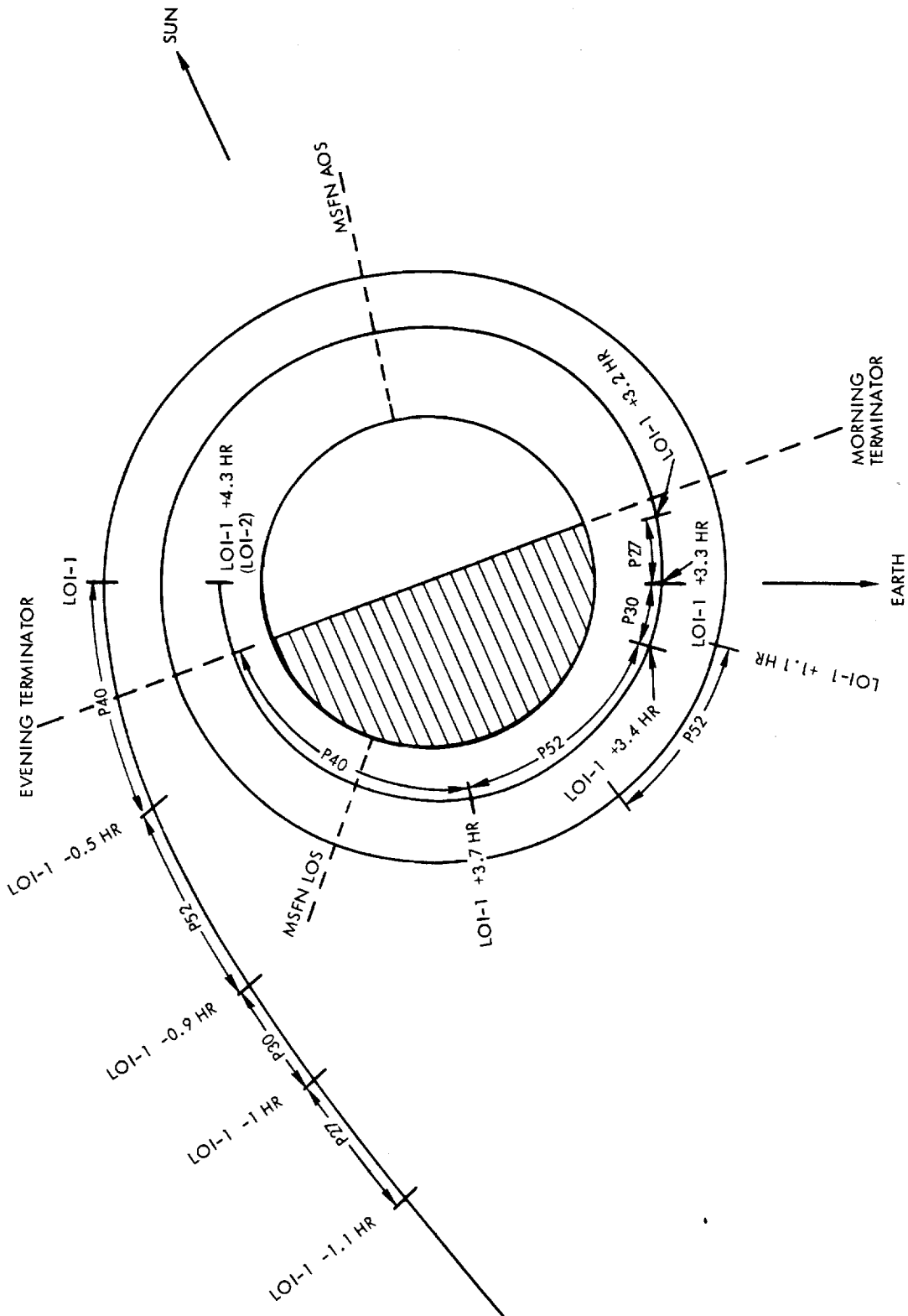


Figure 7. Typical LOI-1 and LOI-2 Events Sequence

Since presently LOI-1 is not considered no-go if either BMAG's 1 or BMAG's 2 fail prior to the burn, both SCS attitude displays may not be available for LOI monitoring. If either SCS attitude display is not available, the crew will attempt to use an external reference (stars or horizon) as a gross third vote, if required.

For confirmed rates greater than 10 degrees per second, the Commander (CDR) will turn the translation hand controller clockwise. This places the secondary attitude control system (SCS Rate CMD mode) in command. It also places the secondary SPS actuator system in the TVC control loop and activates the automatic EMS ΔV cutoff. The ΔV counter must be initialized with ΔVC from the PAD data which are compatible with an SCS auto mode burn.

The vehicle attitudes are also monitored by the CDR and CMP. If any attitude errors exceed the allowable limit and are confirmed, the backup mode is selected. The allowable attitude limit is 10 degrees excluding the start transient. This limit was chosen to insure a safe perilune if a manual takeover is necessary.

If an SPS burn is taken over, control may be switched to SCS auto for completion if the peak attitude excursion is under 17 degrees. If the peak attitude excursion exceeds 17 degrees, the BMAG's 1 are no longer properly aligned, so the burn must be completed with SCS RATE CMD control. With this control mode the GDC will be used for steering.

The advantages of continuing the LOI-1 burn under SCS control when a GNCS problem is detected are:

- a) It would be a standard procedure regardless of the type of GNCS problem.
- b) It would provide as much time as needed to analyze and verify the failure.
- c) A premature shutdown during the first half of the LOI-1 burn would require a time-critical return-to-earth burn since abort ΔV would be increasing continuously with time.
- d) A premature shutdown would still require a return-to-earth SCS maneuver--why not make it a near nominal one for which most of the training has been done.

- e) The abort block data would be more nearly applicable.
- f) Some or all of the lunar orbit mission objectives would be obtained.

The GNCS controlled LOI-1 burn will be shut down manually when the burn time exceeds $BT + 6$ seconds. This limit was chosen to make it extremely probable that the GNCS would automatically shut down the SPS if it is going to, and also to assure a safe perilune.

5.9 LOI-2 BURN MONITOR

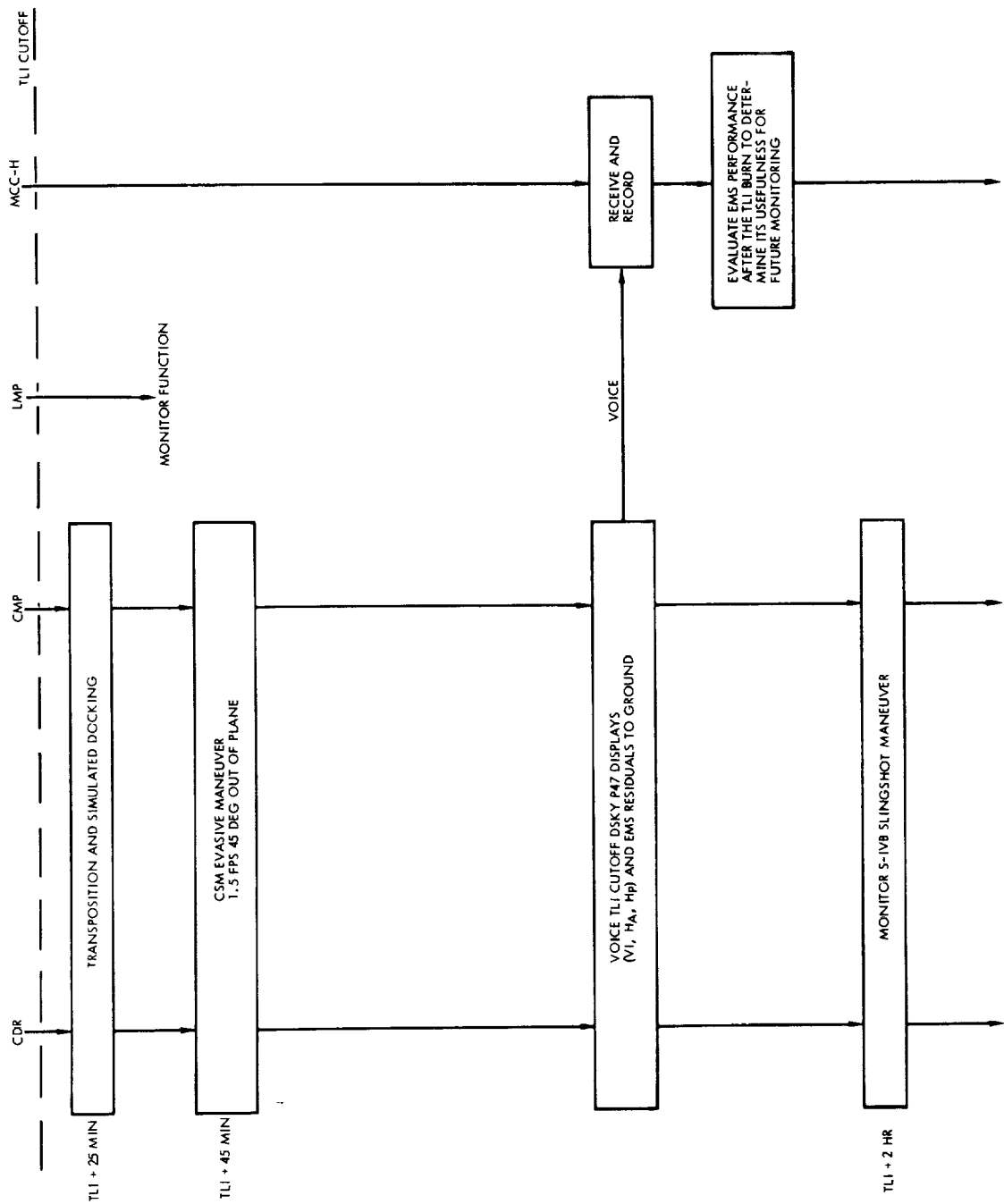
The LOI-2 burn monitoring procedures are very similar to those described for the LOI-1 burn monitor (Section 5.8). Attitude monitoring is unchanged unless the attitude or rate limits (10 degrees and 10 degrees per second excluding the initial attitude transient) are exceeded. In this case the procedure is to switch to the SCS RATE CMD mode, damp rates, and immediately terminate the burn. The shutdown monitor differs in that the LOI-2 burn will be manually terminated if the nominal burn time (PAD data) is exceeded by 1 second.

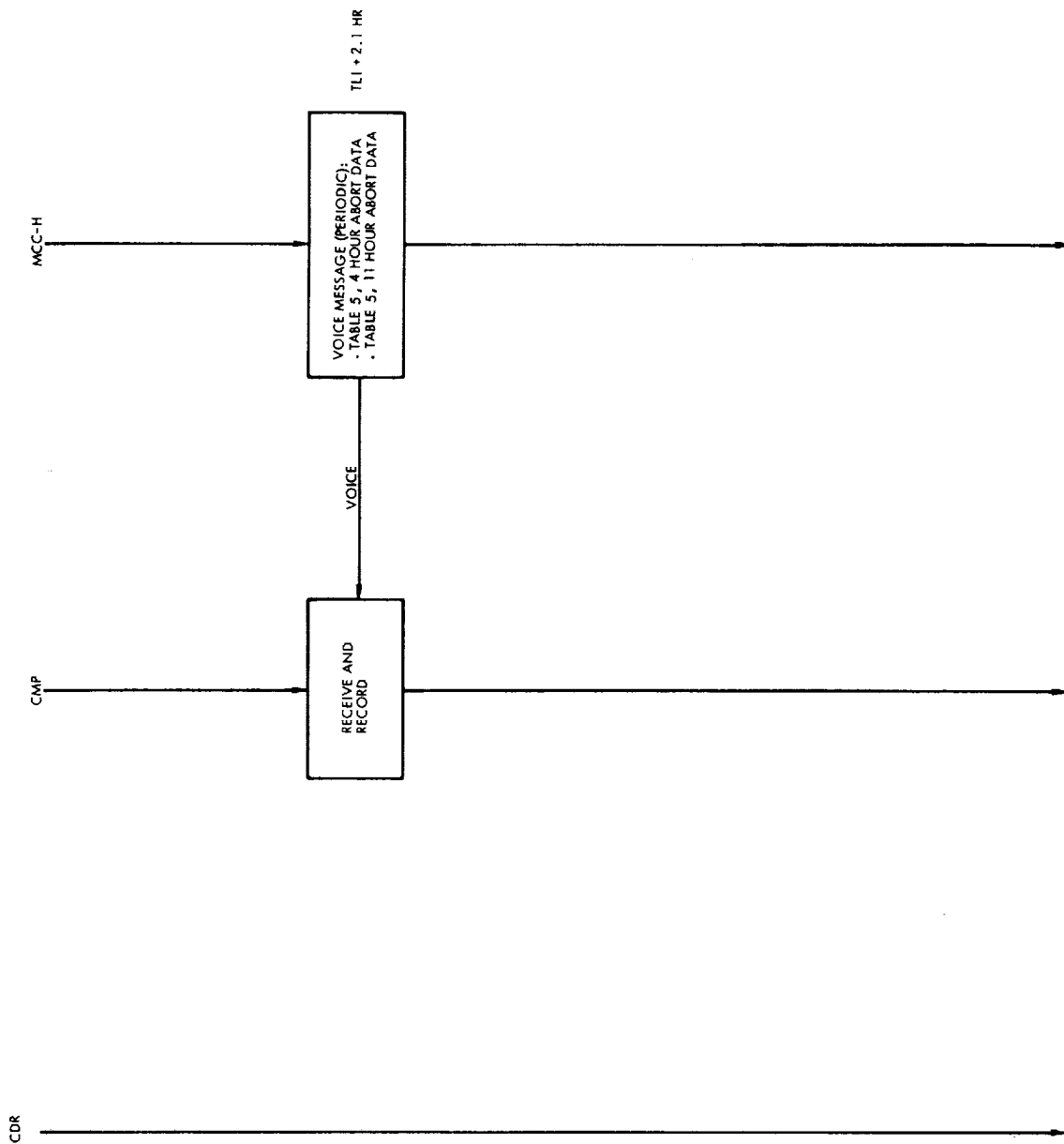
5.10 SPS MIDCOURSE CORRECTION BURN MONITOR

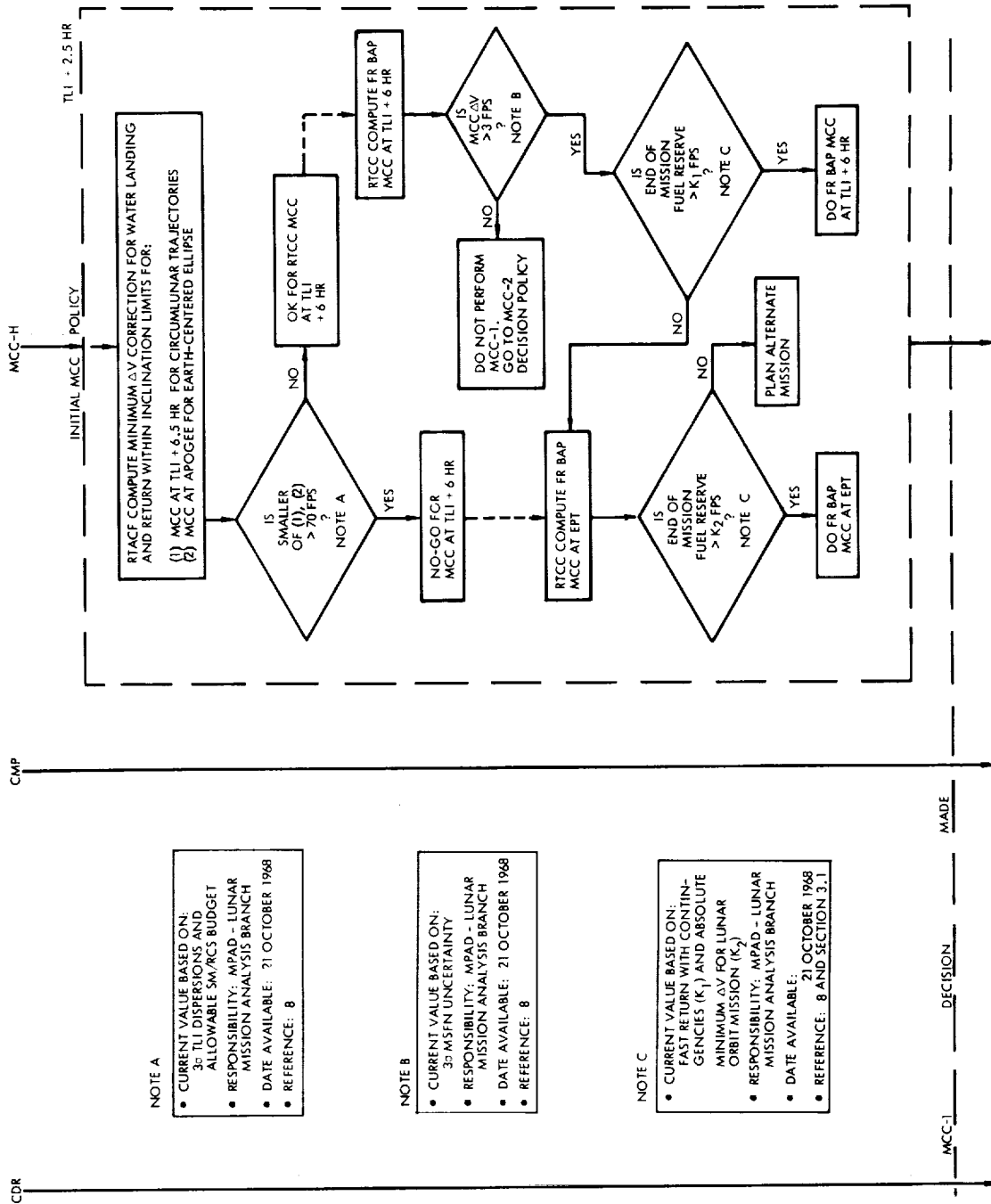
The SPS MCC burn monitoring procedures are similar to those described for the LOI-1 burn monitor (Section 5.8). In the event the attitude or rate limits (10 degrees and 10 degrees per second excluding the starting transient) are exceeded the procedure is to switch to SCS RATE CMD mode, damp rates, and complete the burn. The SPS MCC burns will be manually terminated if the nominal burn time (PAD data) is exceeded by 1 second.

5.11 ABORT (BLOCK DATA) BURN MONITOR

The block data abort burn monitoring procedures are very similar to those described for the LOI-1 burn monitor (Section 5.8). In the event the attitude or rate limits (10 degrees and 10 degrees per second excluding the starting transient) are exceeded the procedure is to switch to SCS RATE CMD mode and damp rates. The burn may then be completed with either the SCS RATE CMD mode or the SCS AUTO mode. Before the burn, ΔVC will be slewed into the EMS ΔV counter. The burn will be terminated manually if the EMS ΔV counter reads less than -1 percent of the burn ΔVC and the burn time is greater than $BT + 1$ percent of BT .







MCC-H

CDR

CMP

TLI + 3.1 HR

SELECT P52 IMU REALIGN
REALIGN TO LAUNCH REFSMMAT

(STANDARD TRANSUNAR P52 TEST)

P52 IMU DRIFT CHECK

NOTE D

- CURRENT VALUE BASED ON:
SIGHTING ACCURACY
- RESPONSIBILITY: MIT
- DATE AVAILABLE: 26 SEPTEMBER 1968
- REFERENCE: 6

NOTE E

- CURRENT VALUE BASED ON:
30 IMU DRIFT
- RESPONSIBILITY: MIT
- DATE AVAILABLE: 26 SEPTEMBER 1968
- REFERENCE: 6

NOTE F

- CURRENT VALUE BASED ON:
ALLOWABLE GYRO DRIFT RATE
- RESPONSIBILITY: MIT
- DATE AVAILABLE: 27 NOV. 1968
- REFERENCE: 5

REPEAT STAR
SIGHTINGS TO
ASSESS PROBLEM

DO GYRO
TORQUING ANGLES
INDICATE DRIFT
RATES < 1.5 DEG/HR
NOTE F

PERFORM MCC WITH SCS

PERFORM PERIODIC P52
IMU REALIGNMENTS.
RECORD GYRO TORQUING
ANGLES AND VOICE TO
MCC-H FOR IMU PERFORMANCE
EVALUATION. PERFORM MCC
WITH GNCS

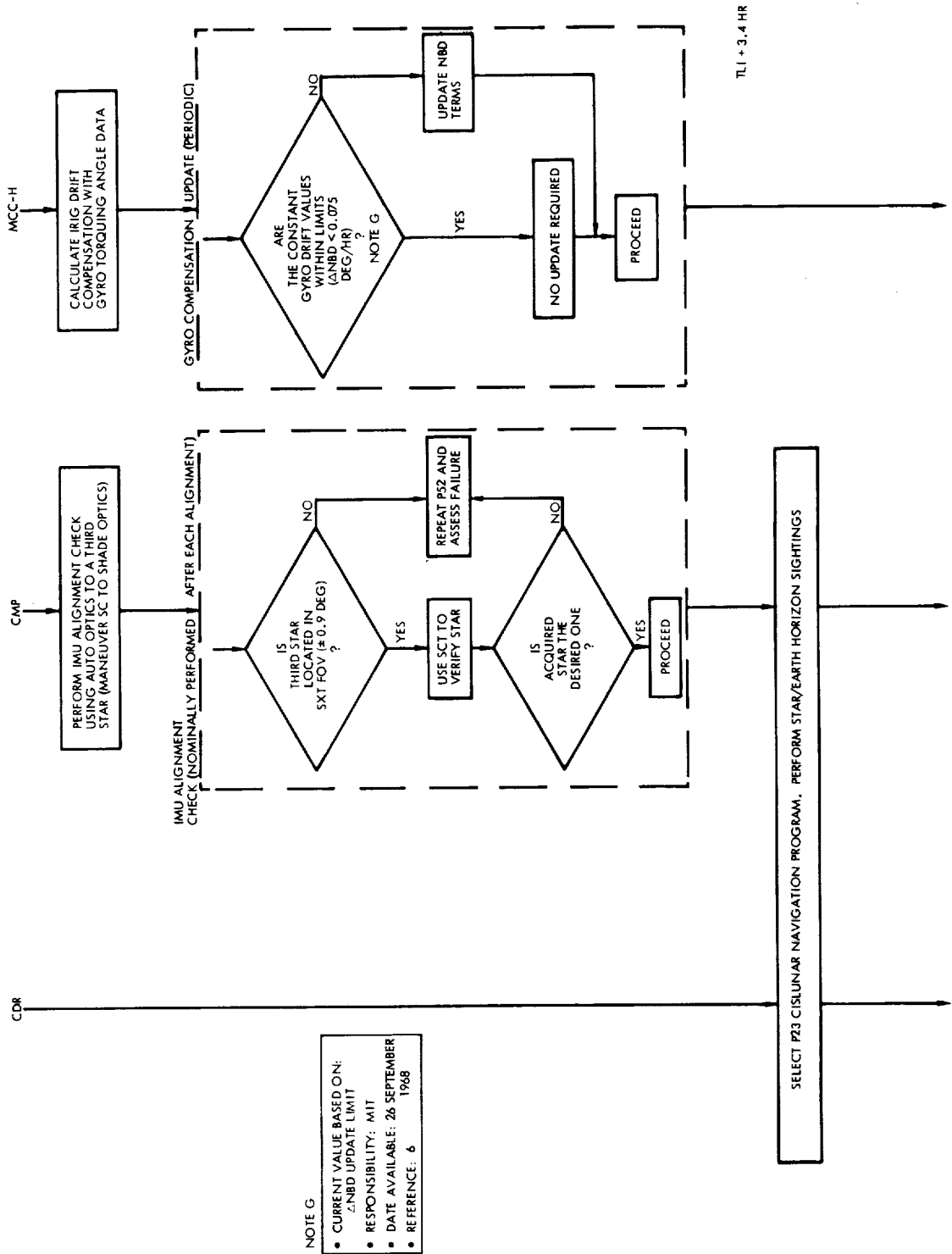
* IF THIS IS FIRST P52 SINCE
LIFT-OFF, G-SENSITIVE
DRIFT AND INITIAL MIS-
ALIGNMENT MUST BE
FACTORED IN.

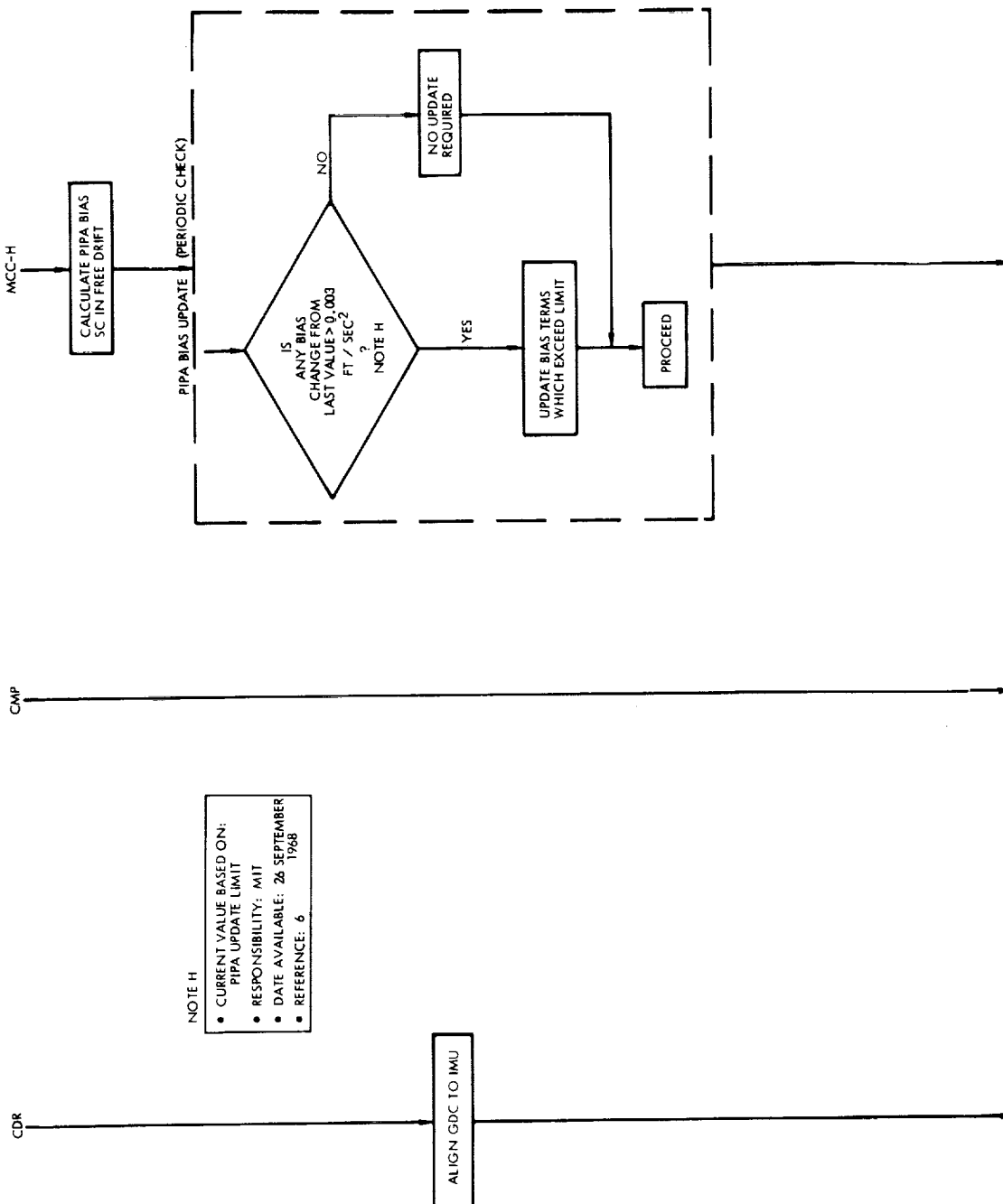
ENABLE GYRO TORQUING

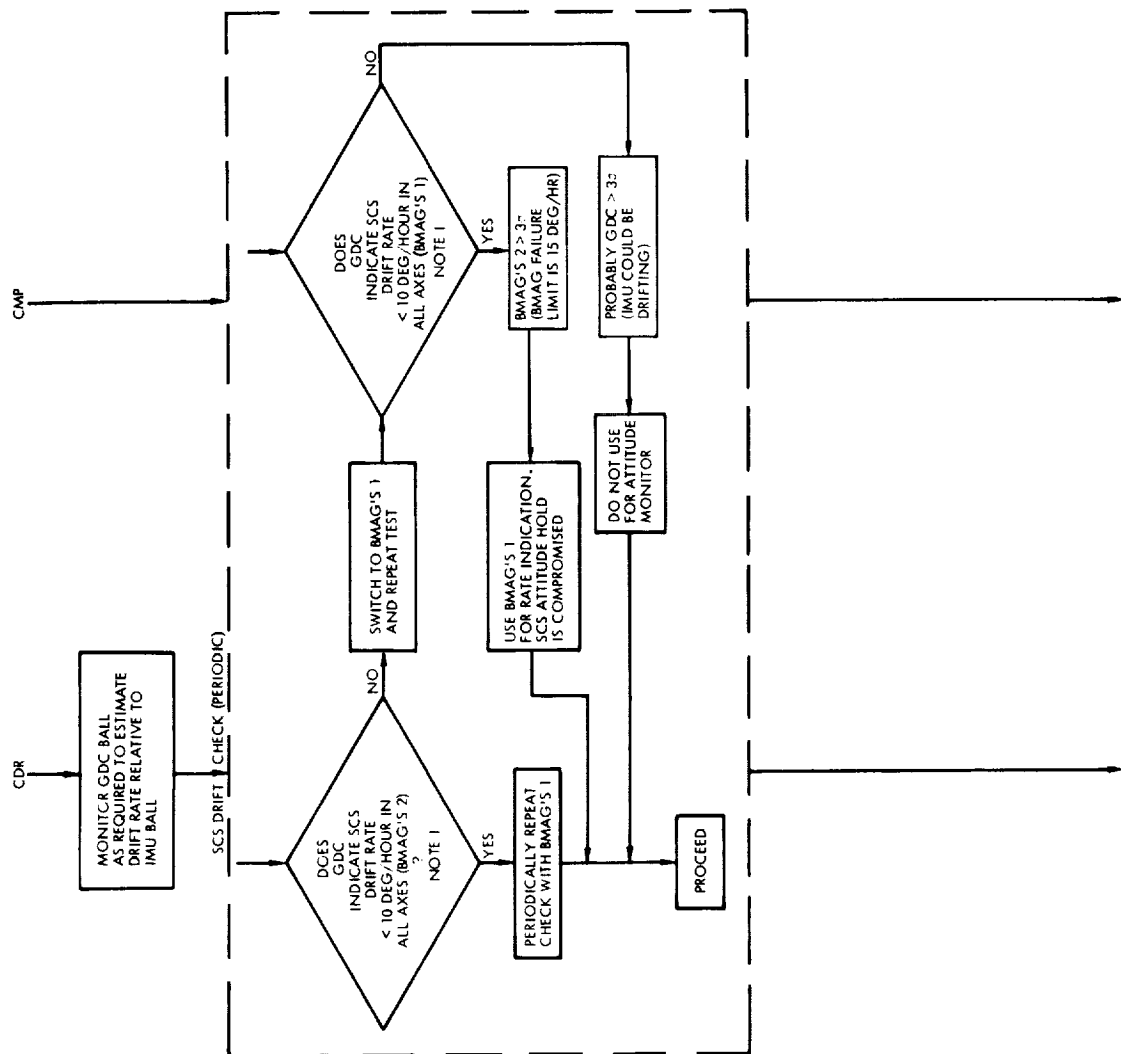
PROCEED

IS
STAR
DIFFERENCE
ANGLE < 0.05 DEG
NOTE D

DO GYRO
TORQUING ANGLES
INDICATE DRIFT
RATES $< 0.09^{\circ}$ DEG/HR
NOTE E

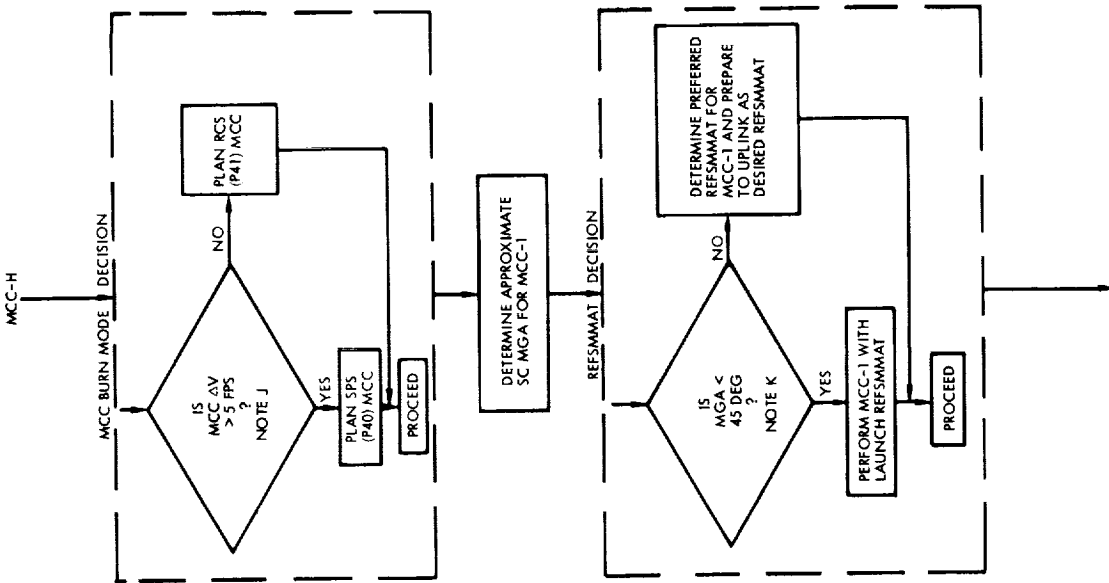






NOTE 1

- CURRENT VALUE BASED ON: 30 SCS DRIFT LIMIT
- RESPONSIBILITY: NR
- DATE AVAILABLE: 4 NOV 1968
- REFERENCE: 16



NOTE J

- CURRENT VALUE BASED ON: SPS VS. RCS CROSSOVER
- RESPONSIBILITY: MPAD - GUIDANCE AND PERFORMANCE BRANCH
- DATE AVAILABLE: 21 OCTOBER 1968
- REFERENCE: 9

NOTE K

- CURRENT VALUE BASED ON: ALLOWABLE MIDDLE CMBAL ANGLE EXCURSION
- RESPONSIBILITY: MPAD - LUNAR MISSION ANALYSIS BRANCH
- DATE AVAILABLE: 27 SEPTEMBER 1968
- REFERENCE: 19

MCC-H

CDR

CDR

SET EMS SWITCH
TO ΔV SET AND
SLEW 1586.8 FT/SEC
INTO COUNTER;
SET SWITCH TO
ΔV TEST

EMS ΔV COUNTER CHECK

DID
EMS ΔV DISPLAY
COUNTDOWN TO
-20.8 ± 20.7 FT/SEC?
NOTE L

NO

FAIL EMS COUNTER
OR IF TIME PERMITS,
PERFORM AOH
MALFUNCTION
PROCEDURES

YES

PROCEED

PLACE SPACECRAFT
IN DRIFTING FLIGHT
WITH NO RCS FIRING
AND SET EMS SWITCH
TO ΔV POSITION

EMS ACCELEROMETER BIAS CHECK

DOES
EMS ΔV COUNTER
INDICATE > 10.0 FT/SEC
AFTER 100-SEC PERIOD?
NOTE M

NO

YES

EMS FAIL. DO
NOT USE COUNTER TO
MONITOR MCC BURN

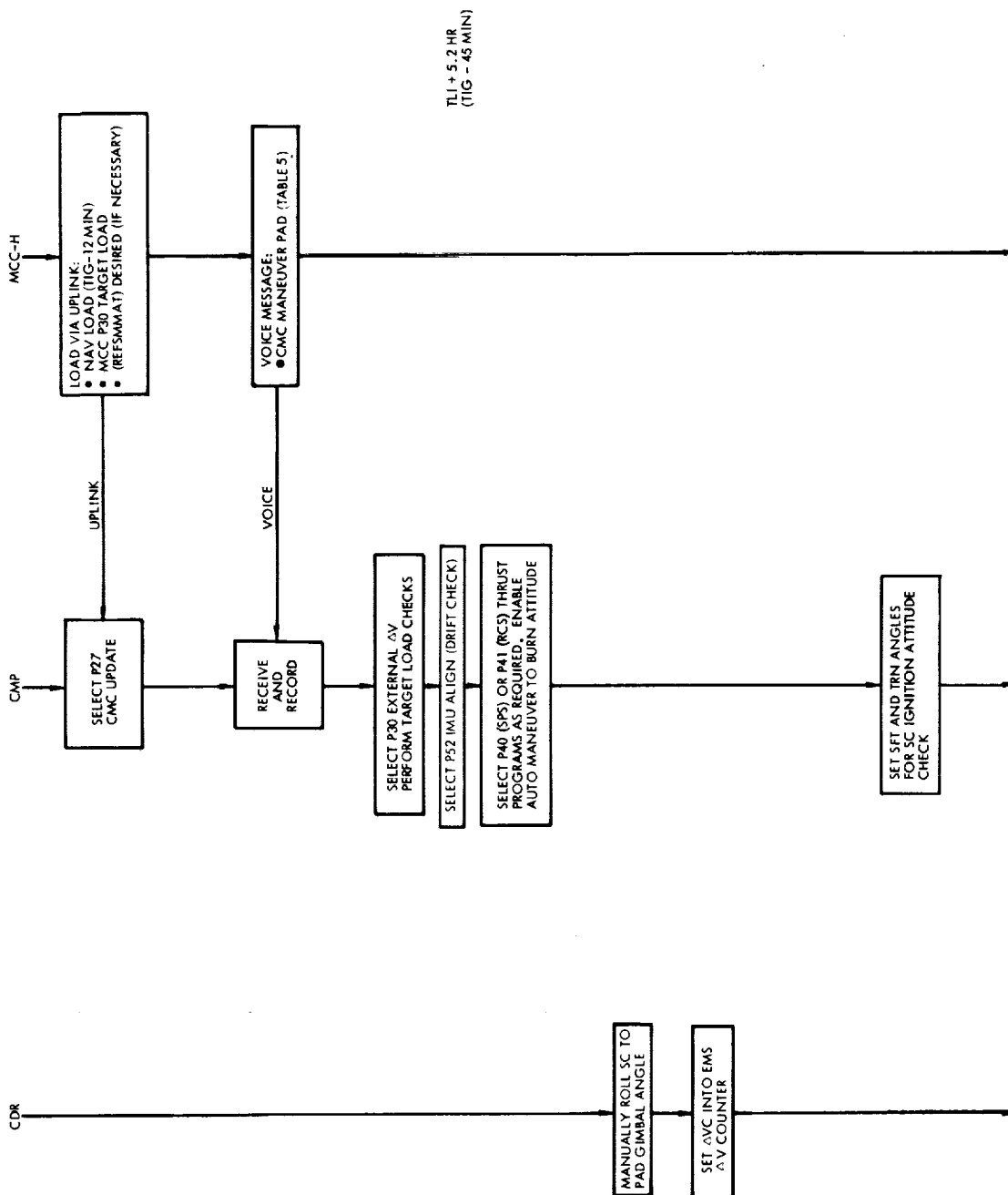
PLAN TO USE
EMS TO
MONITOR GNCS

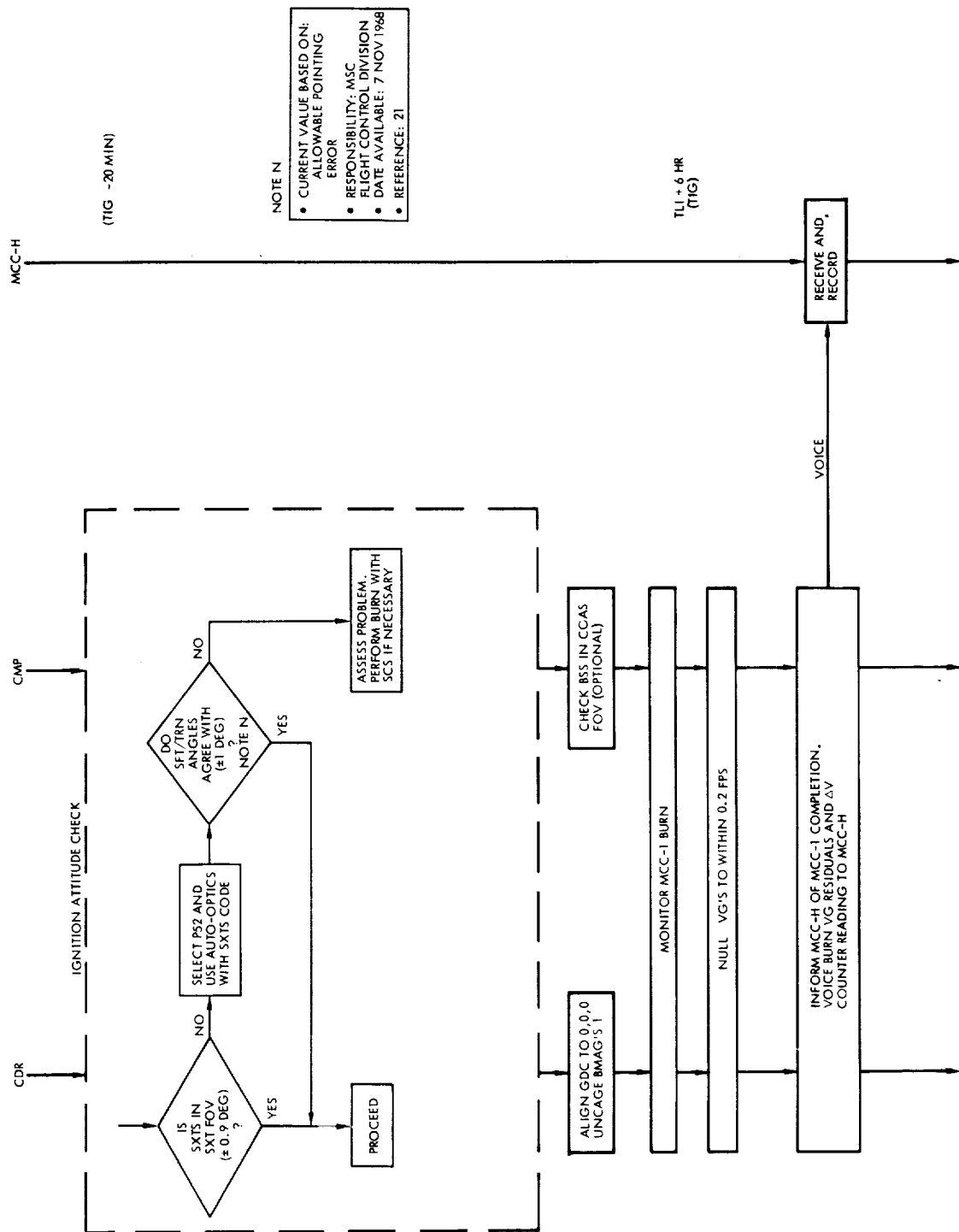
NOTE L

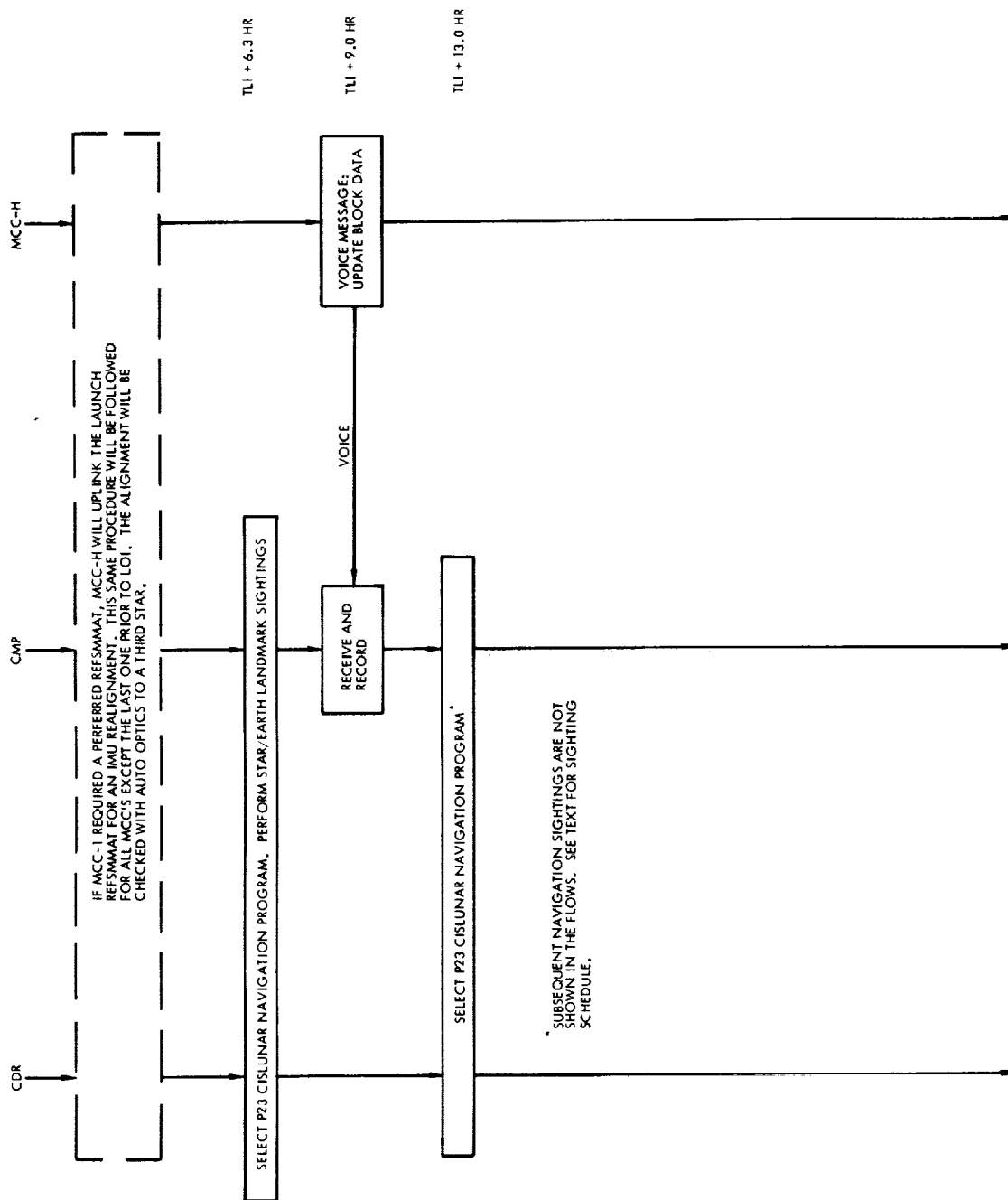
- CURRENT VALUE BASED ON:
AOH PROCEDURES
- RESPONSIBILITY: AOH
- DATE AVAILABLE: 20 NOV. 1968
- REFERENCE: 20

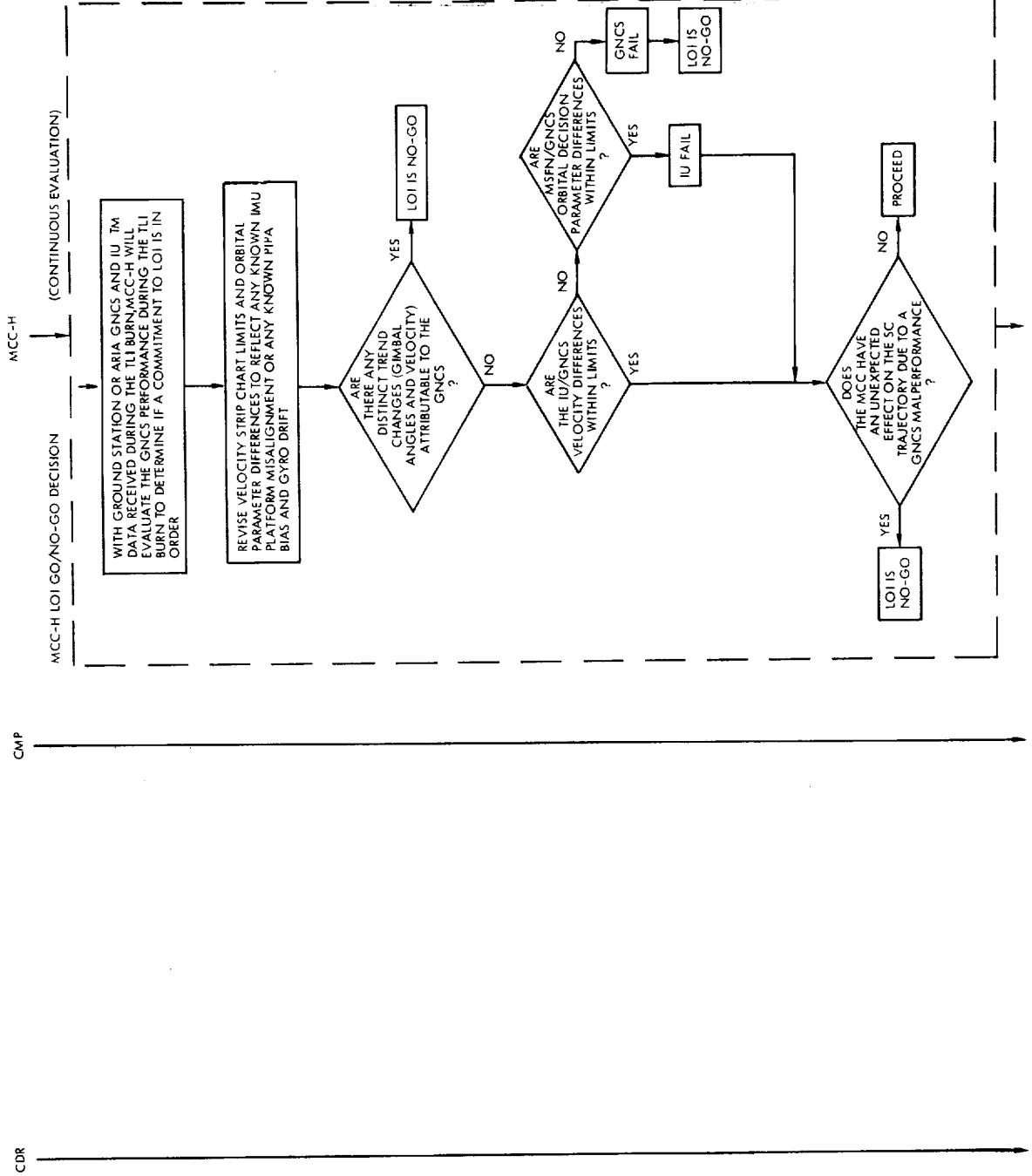
NOTE M

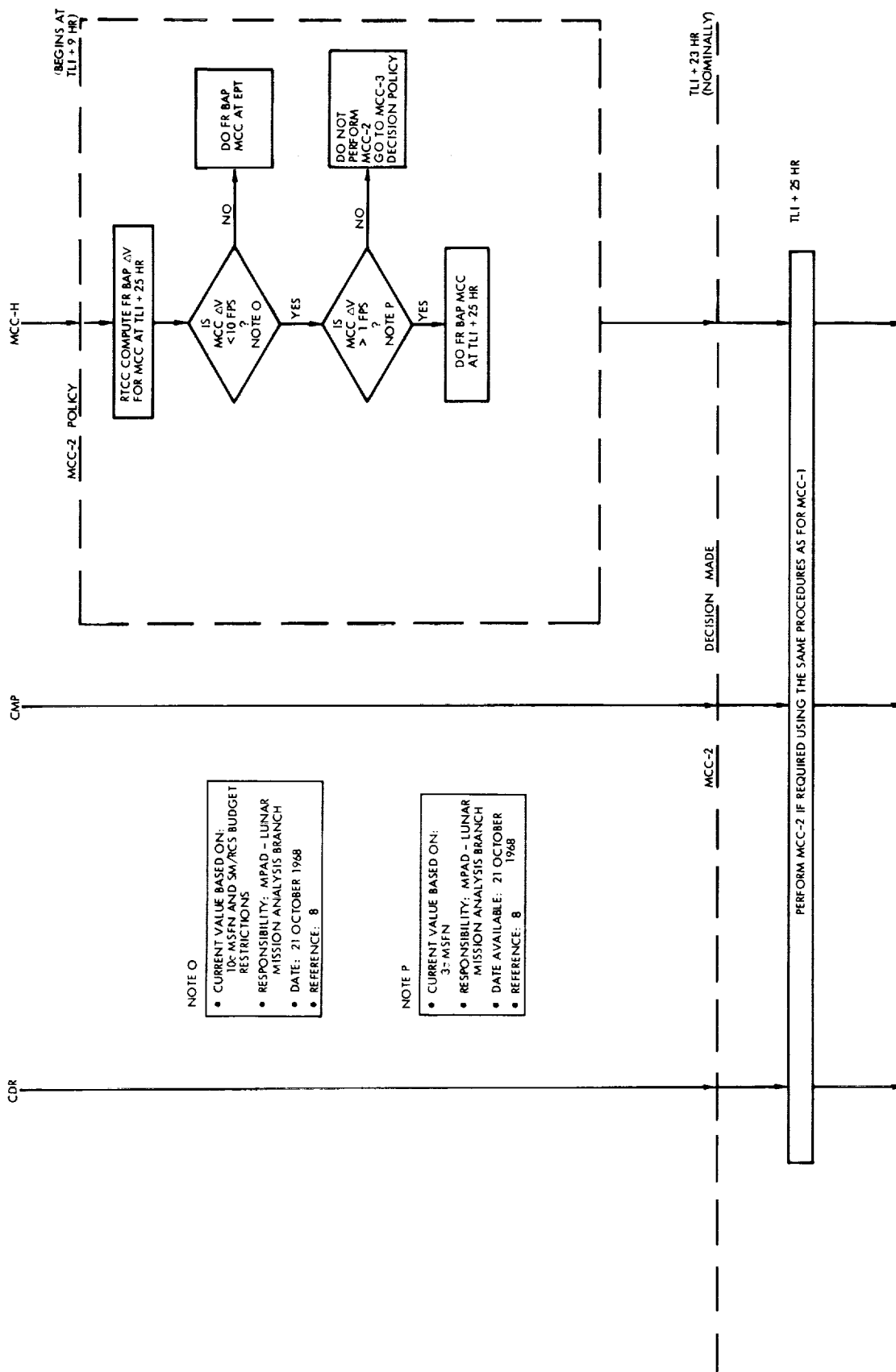
- CURRENT VALUE BASED ON:
ALLOWABLE EMS BIAS VALUE
- RESPONSIBILITY: NR
- DATE AVAILABLE: 12 DECEMBER
1968
- REFERENCE: 17

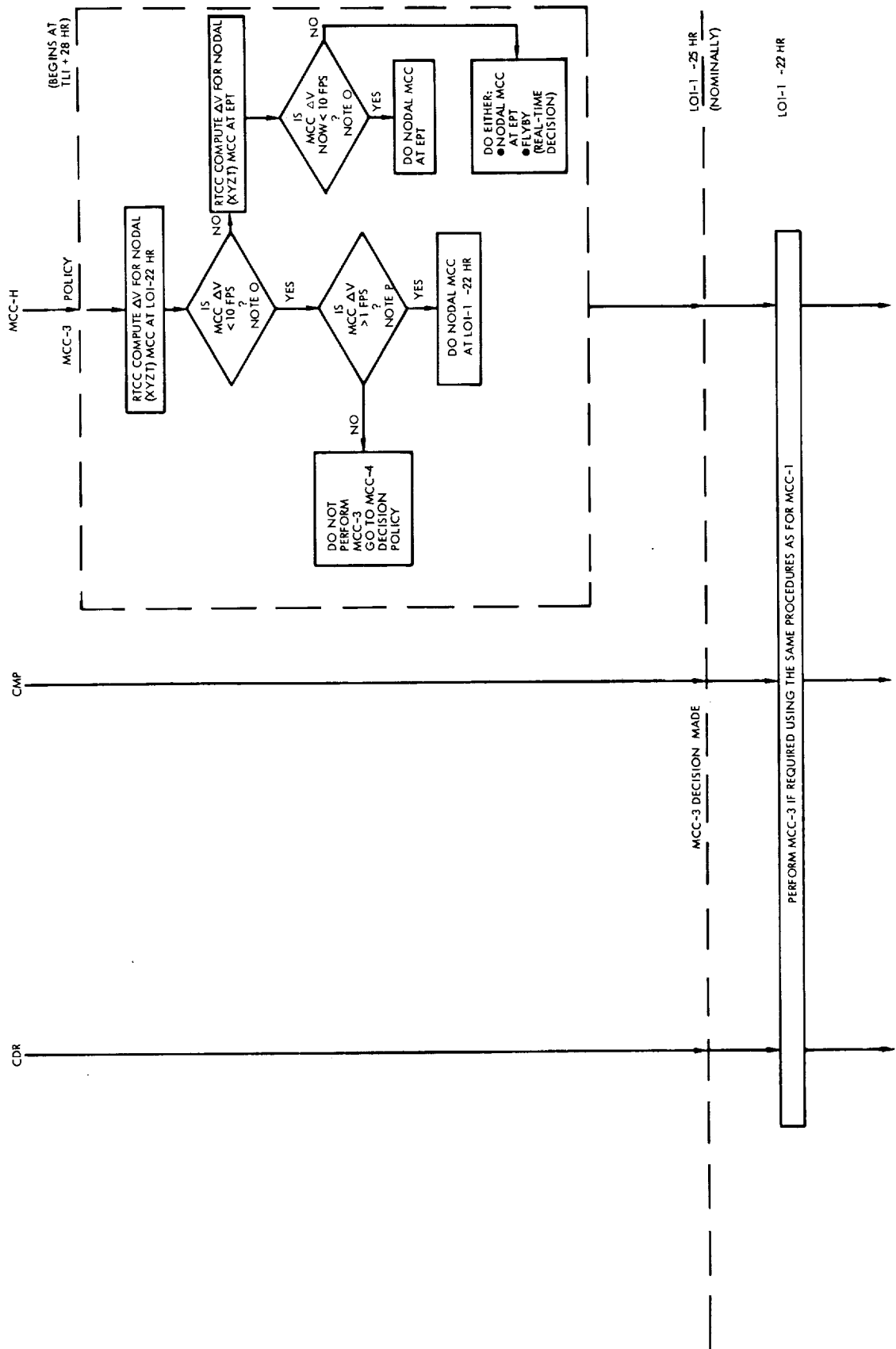


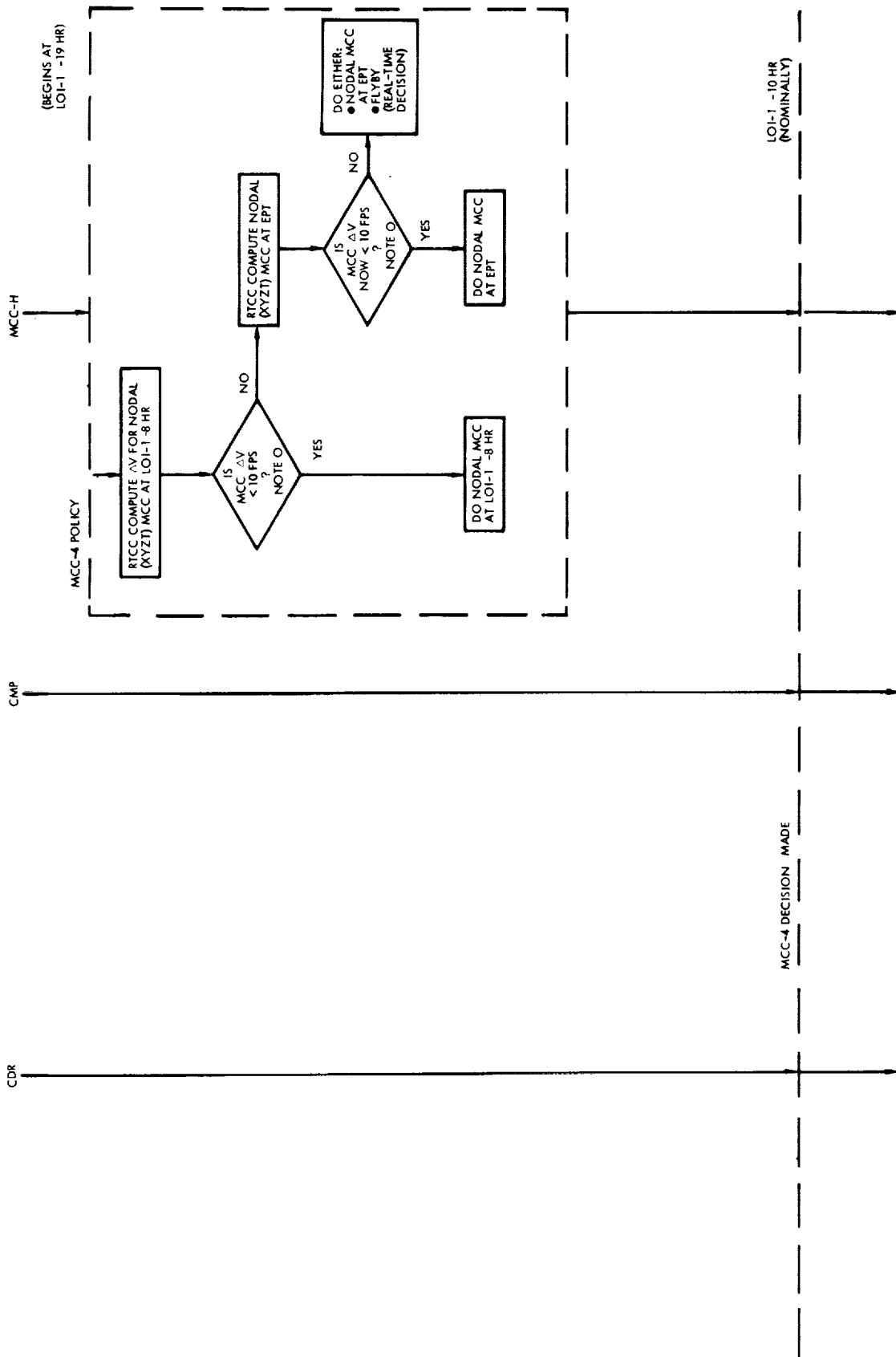


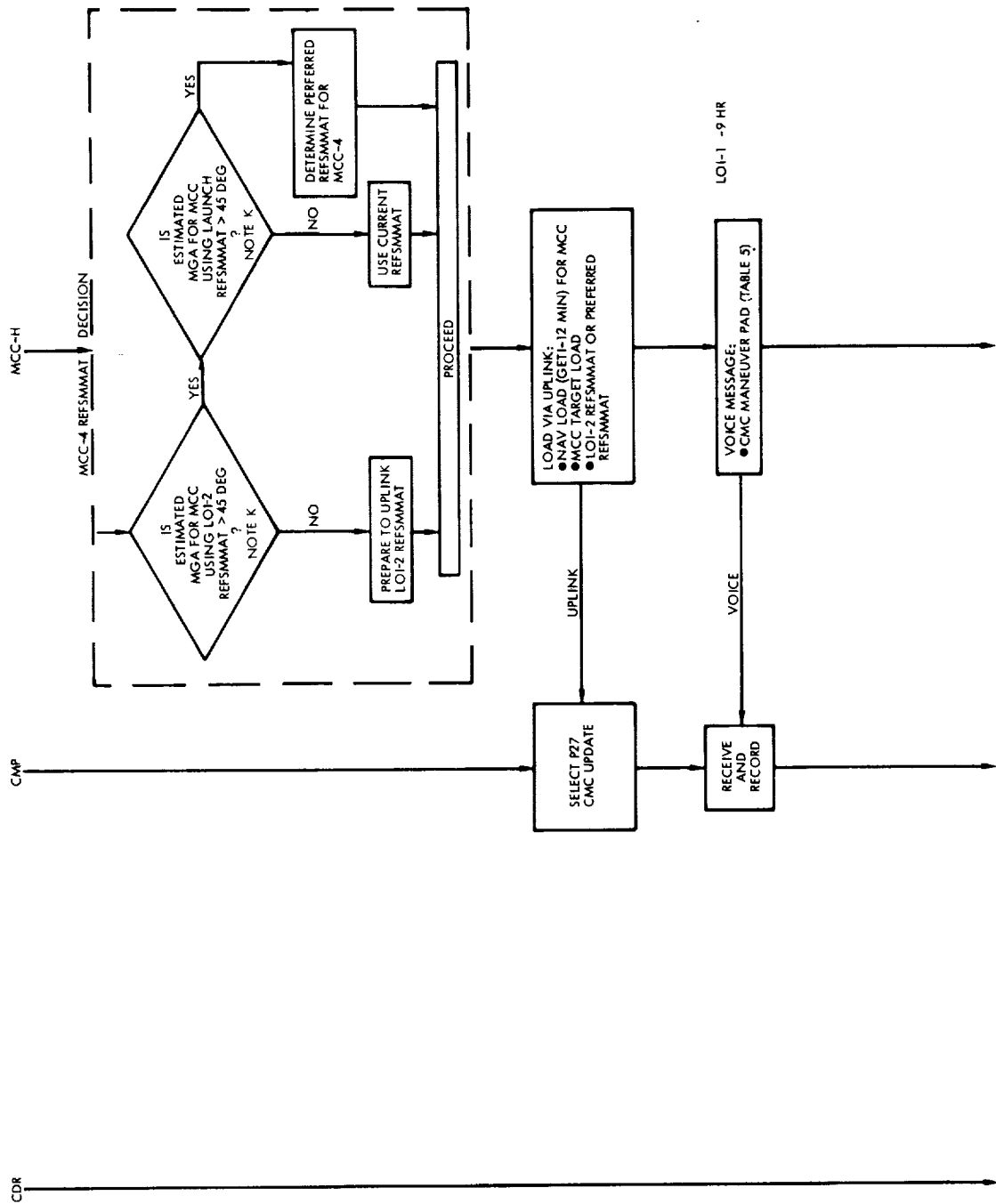


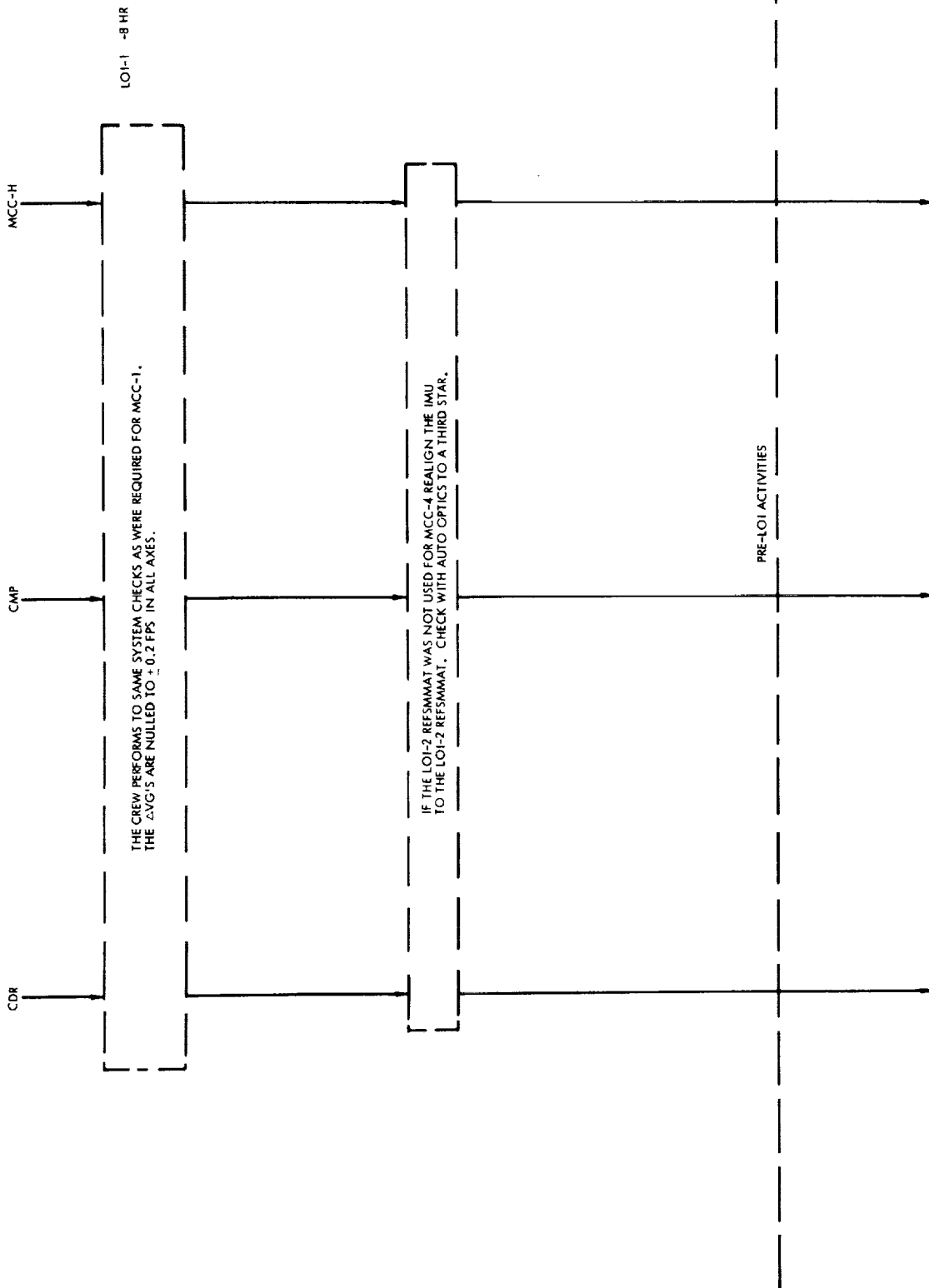


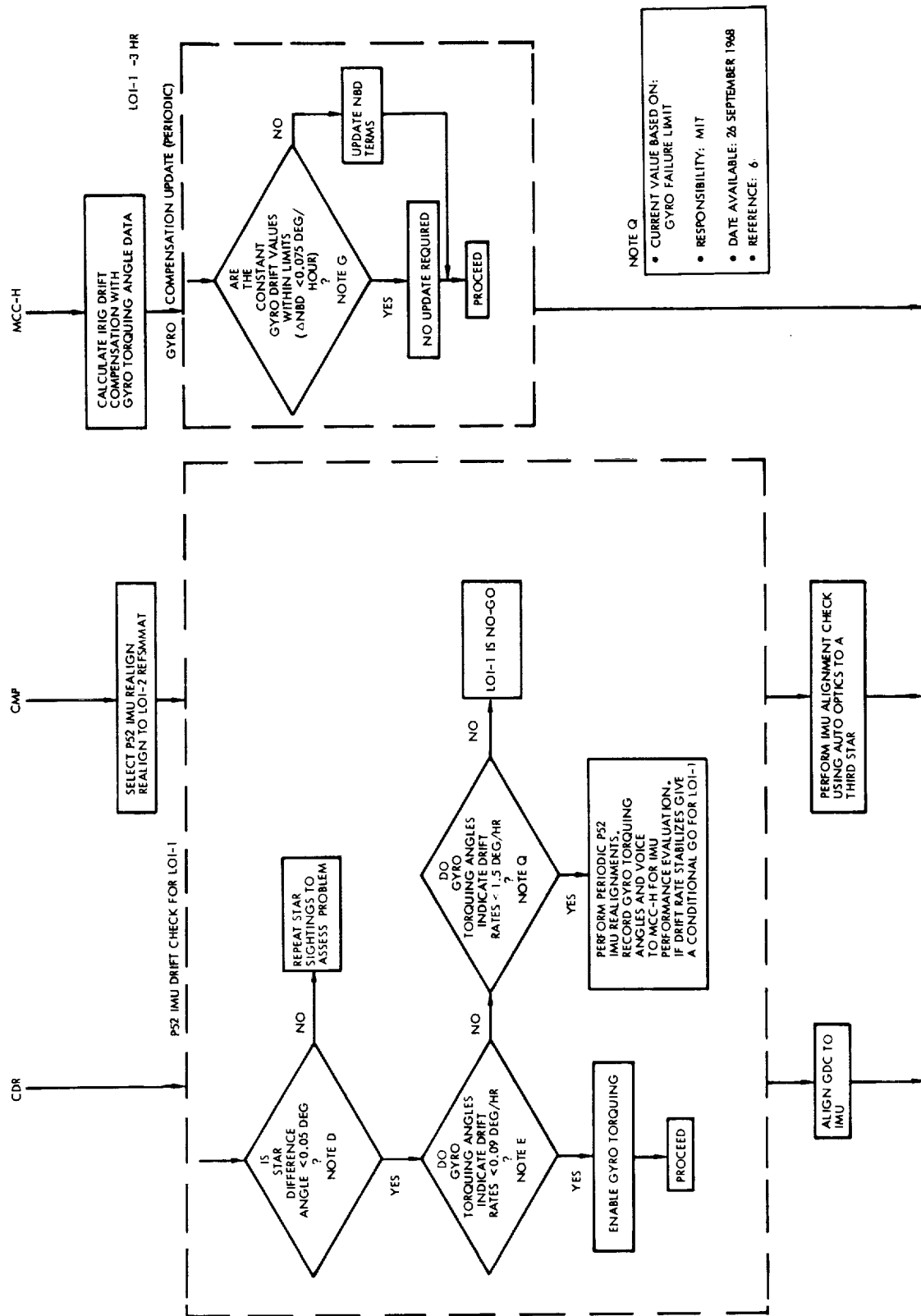


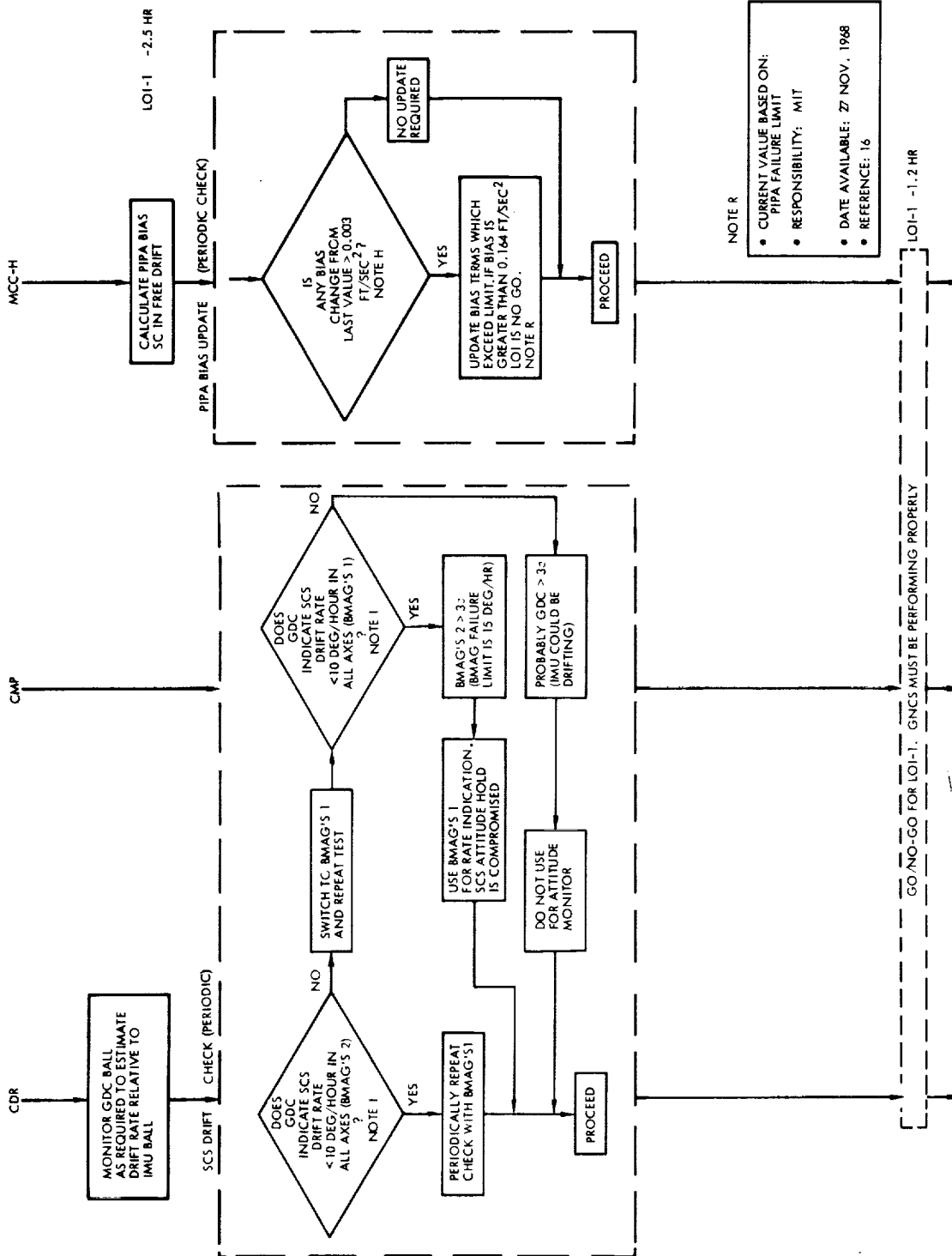






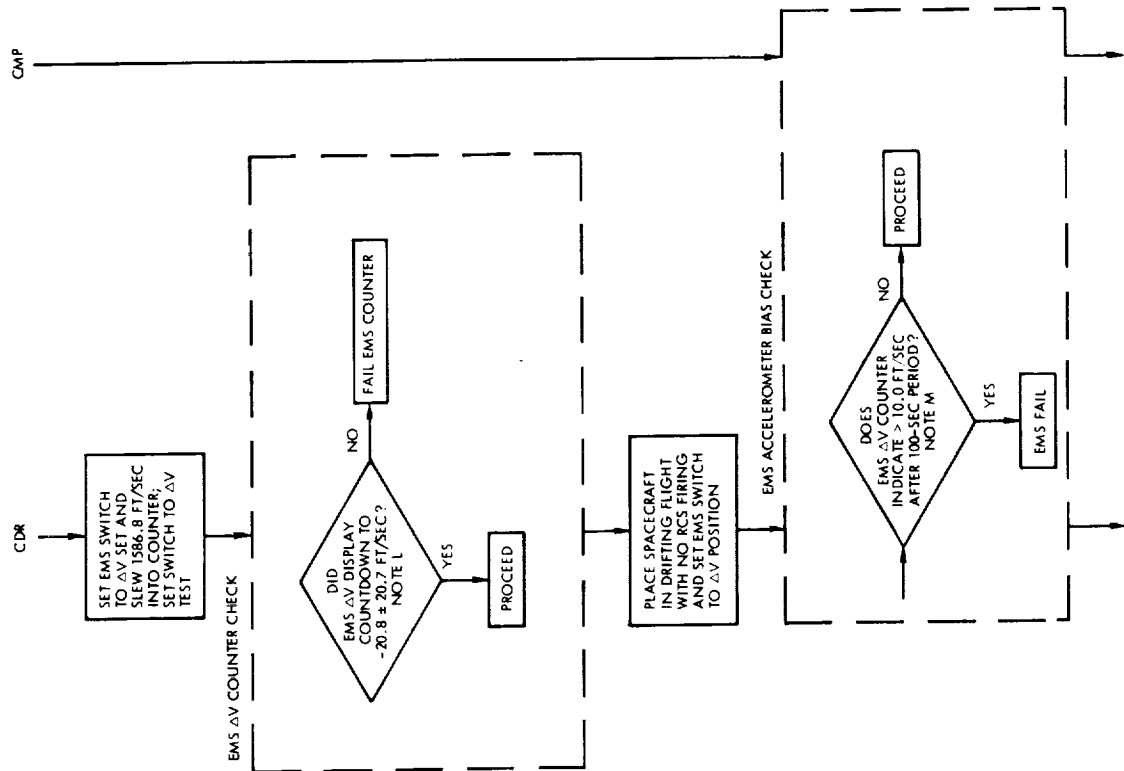


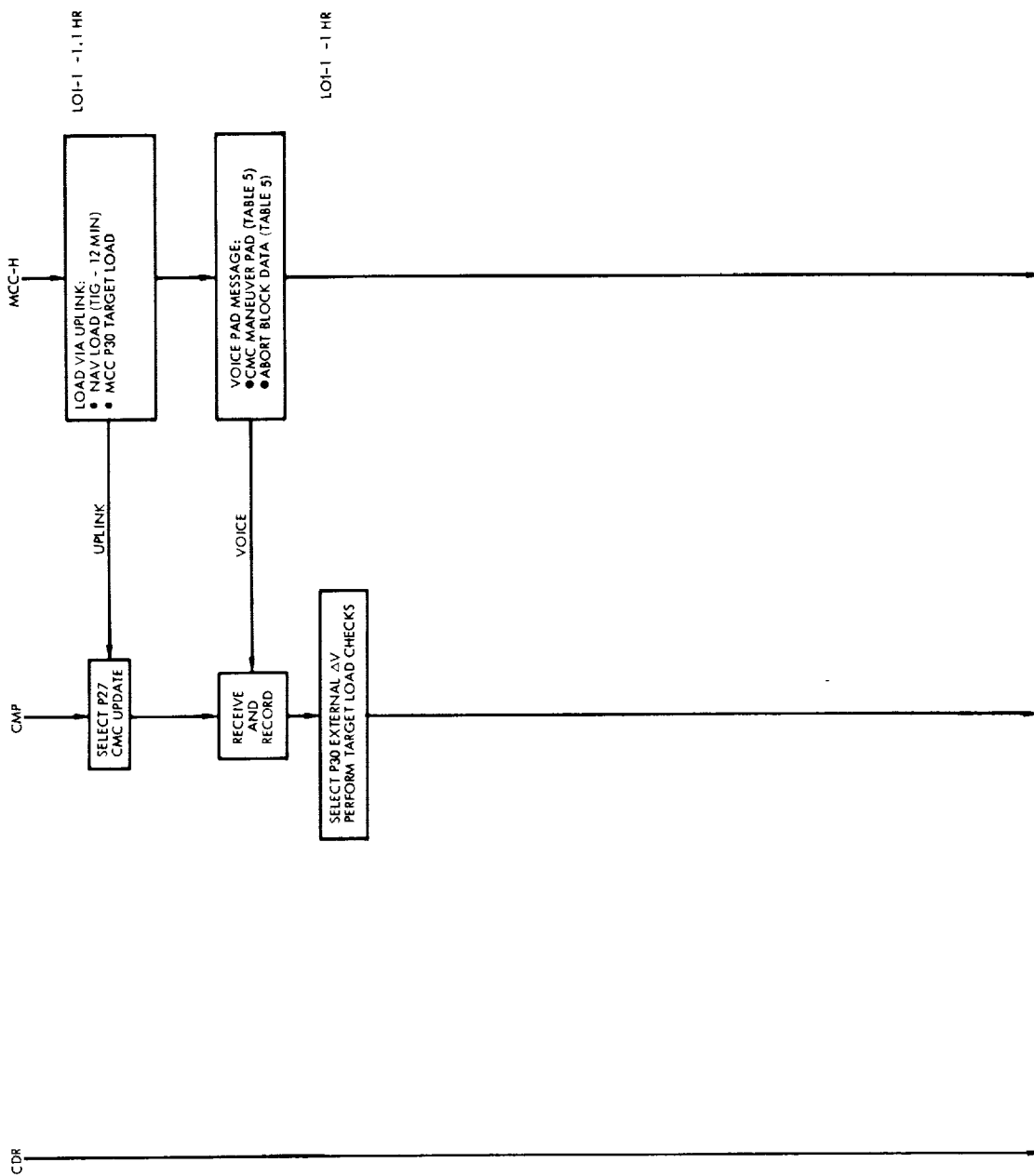


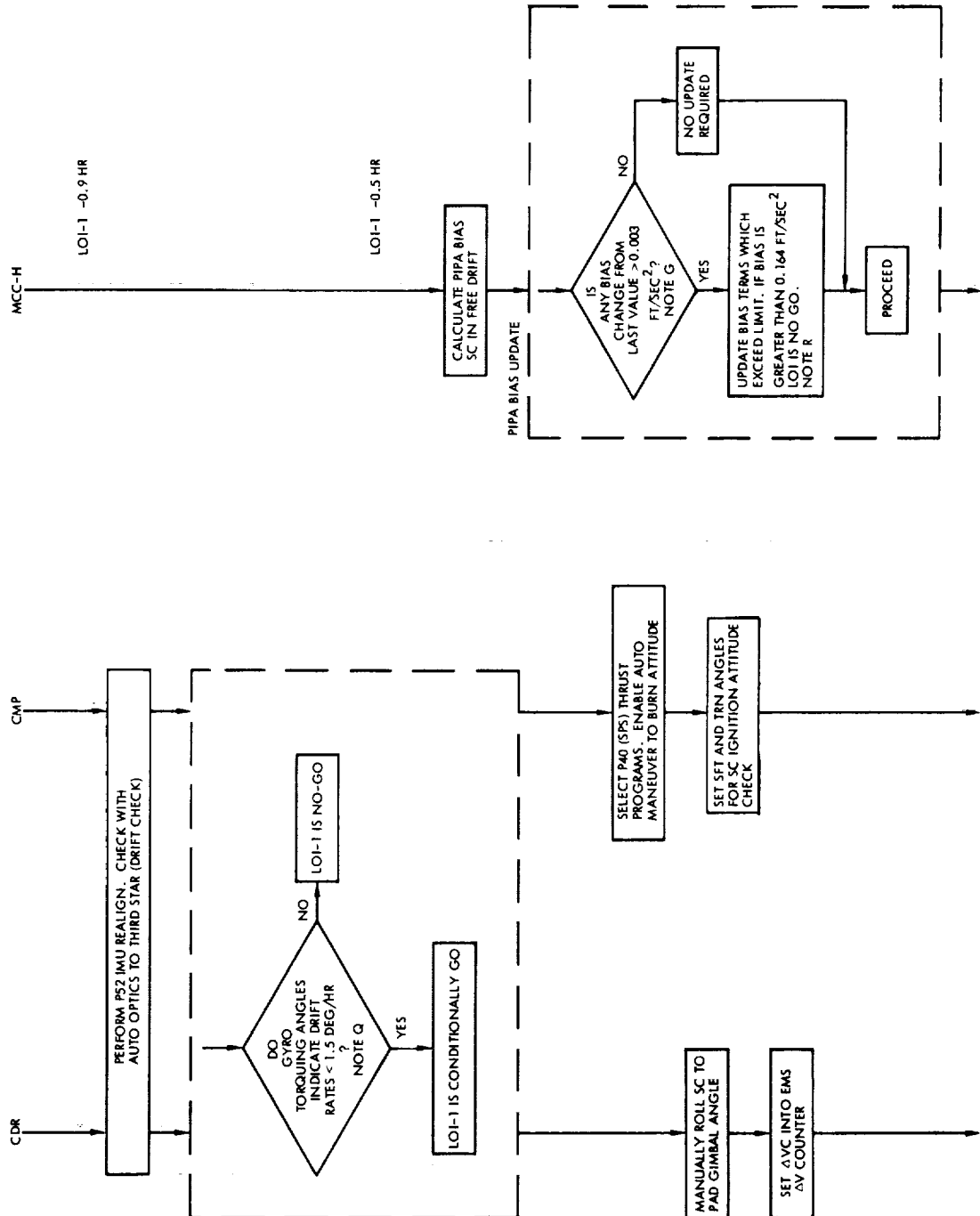


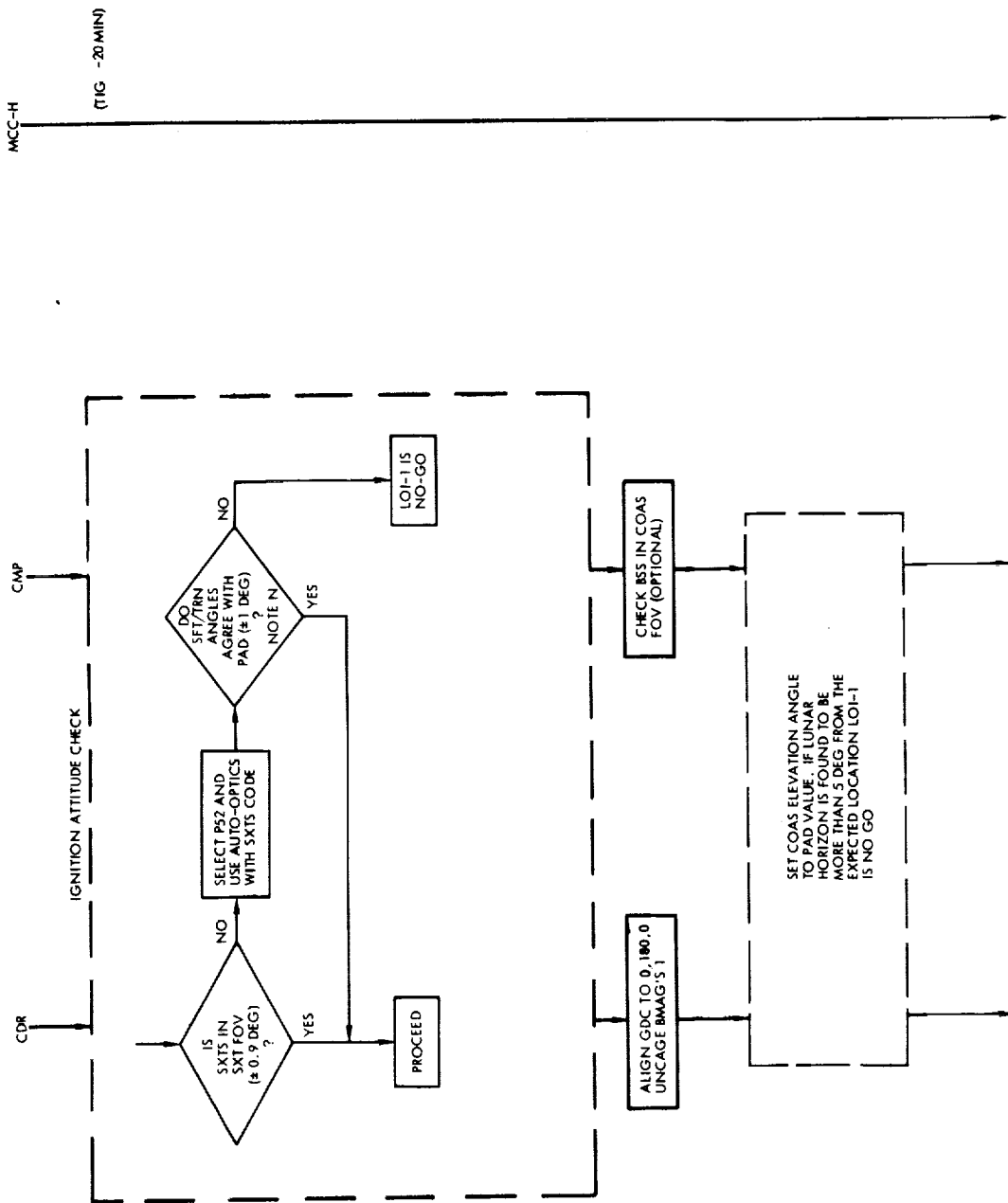
MCC-H

CMP

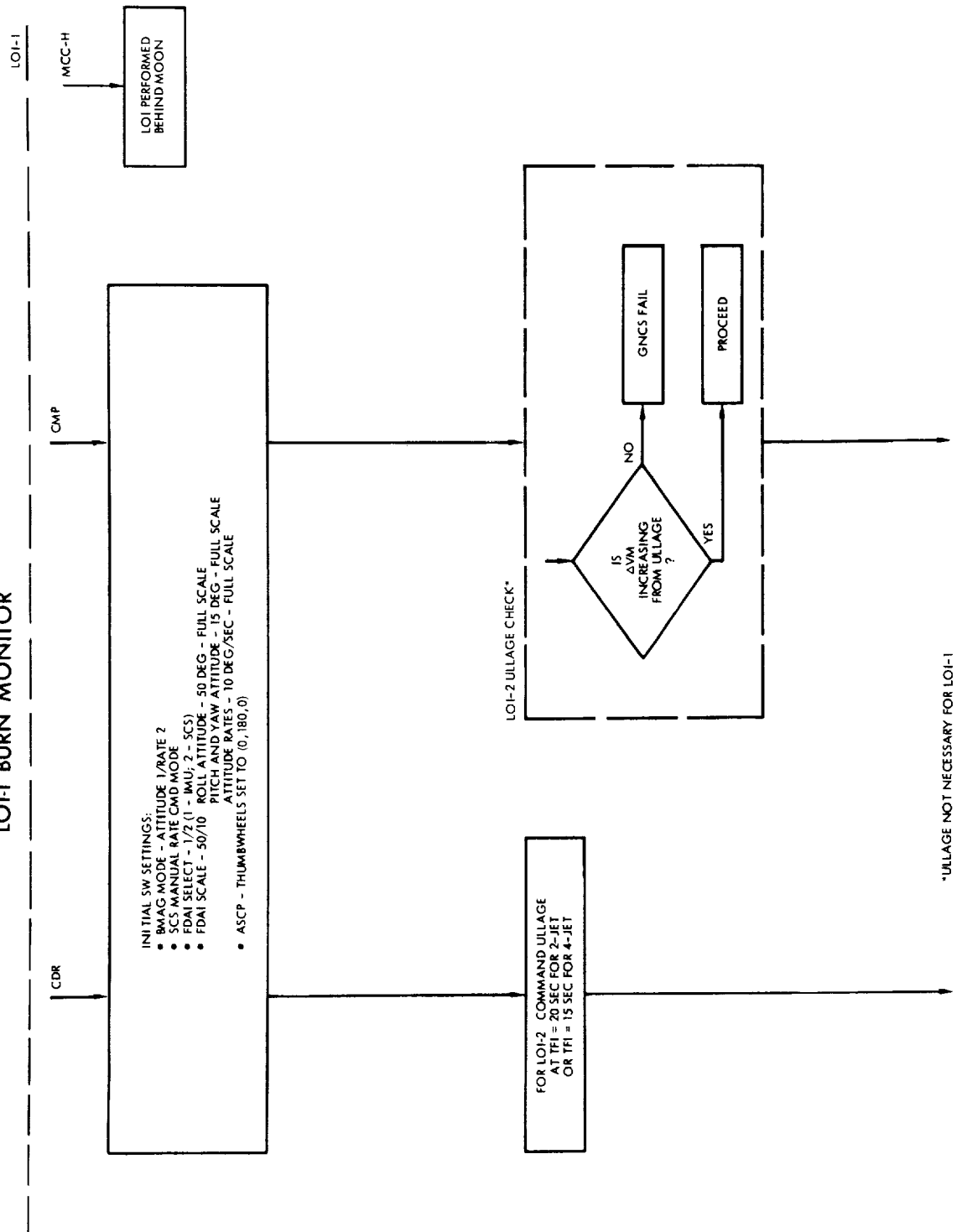








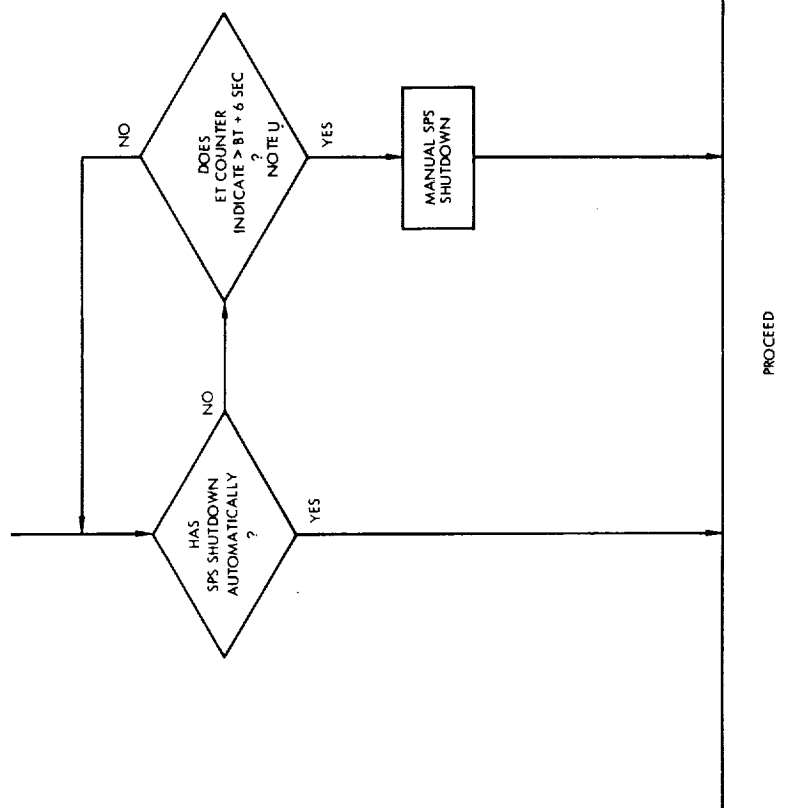
LOI-1 BURN MONITOR



SPS SHUTDOWN MONITOR

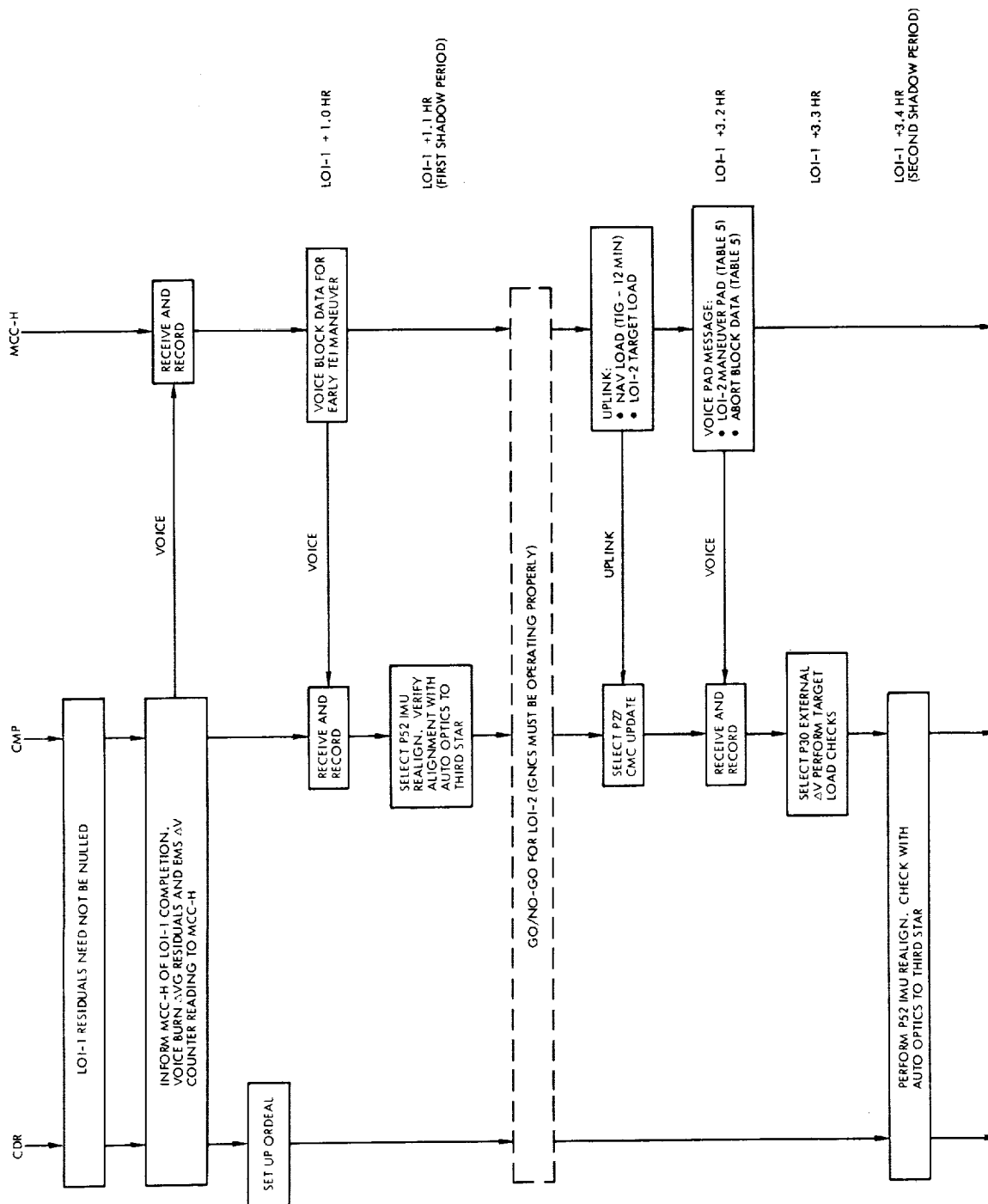
CDR

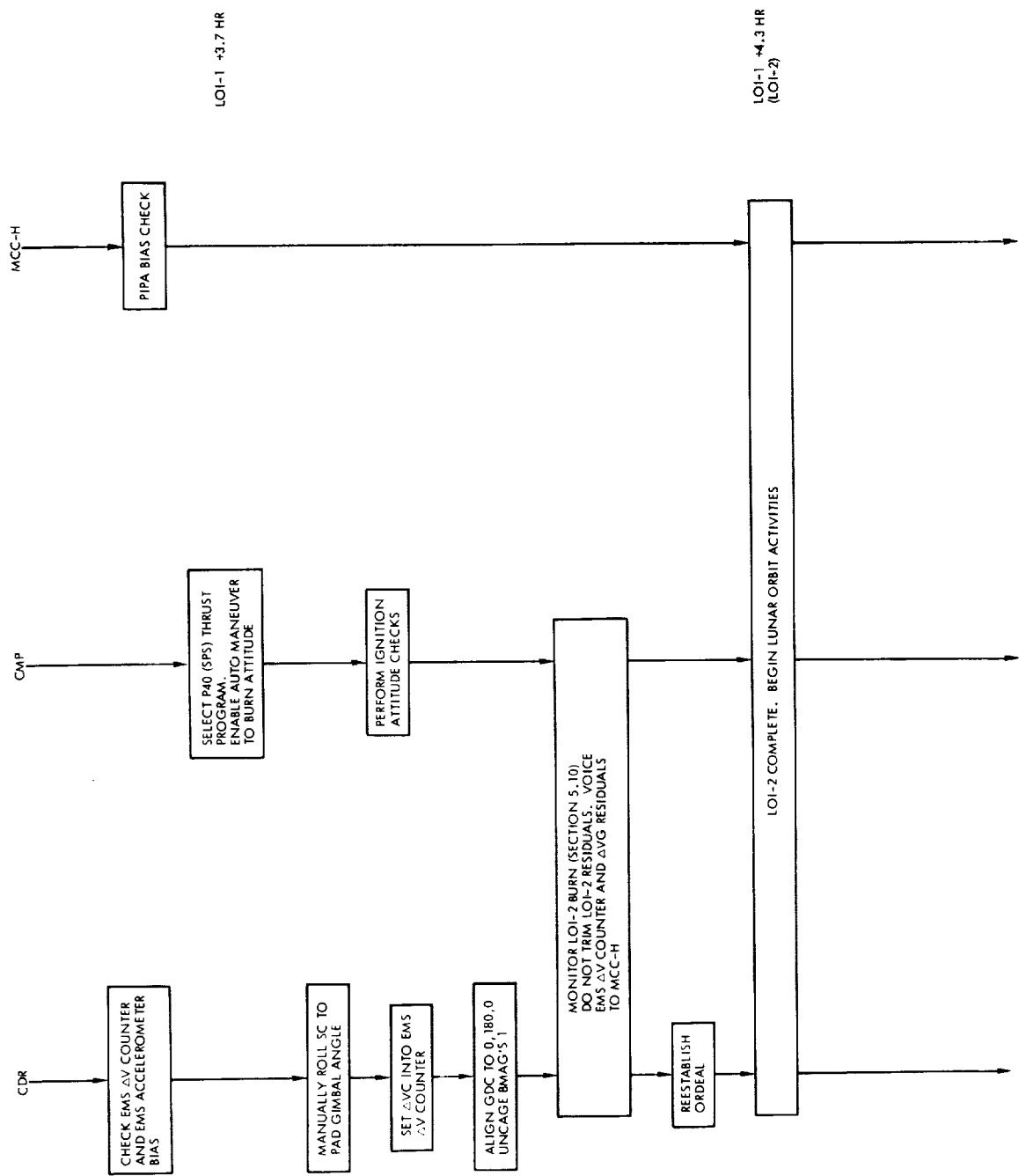
CMP

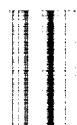


NOTE U

- CURRENT VALUE BASED ON:
LOI-1 SHUTDOWN
LIMIT
- RESPONSIBILITY MPAD - GUIDANCE
AND PERFORMANCE BRANCH
- DATE AVAILABLE: 22 NOVEMBER 1968
- REFERENCE: 18







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20. "CSM 103 Apollo Operations Handbook, Volume 2, Operational Procedures," SM 2A-03-SC103-(2), 20 November 1968.
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22. H. W. Tindall, "C-prime Spacecraft Navigation Mission Techniques," 68-PA-T-229A, 22 October 1968.

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